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Calvin F. Swingle
EDITOR IN CHIEF

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LOCOMOTIVE BOILERS

CARE AND OPERATION

INCLUDING

FIREMAN'S DUTIES, HEAT AND FUEL COMBUSTION

VOL. I
ILLUSTRATED

BY
CALVIN F. SWINGLE, M. E.
AND A CORPS OF PRACTICAL MECHANICAL EXPERTS

PUBLISHERS
NATIONAL INSTITUTE OF PRACTICAL MECHANICS
CHICAGO, ILL.

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LOCOMOTIVE BOILERS—CARE AND OPERATION.

FIREMAN'S DUTIES.

One of the most important duties of a fireman is to form the habit of being "on time," if possible. He should be on his engine at least thirty minutes before the engine leaves the house. He will then have time to get everything in good shape.

First see that the water supply is right, then the coal wet down, cab swept out and windows cleaned, oil cans all filled and in their places, and lamps cleaned and filled with oil. He should also be sure that all needed supplies, such as flags, lanterns, torpedoes, waste, etc., are on hand, and of the right kind.

He should carefully examine the fire-box to see if there are any leaks that would be a detriment to the fire, or the draft, thus causing the engine to steam poorly.

He should also know that the grates are clean and can be worked, that the dampers are in the proper position and can be closed when necessary, and see that there are no openings in the smoke-arch such as poor fitting peephole covers or hopper valve that would have a tendency to decrease the draft and cause poor steaming.

Another important point, and one in which he is particularly interested, is that the engine is supplied with the proper fire tools—clinker bar, ash pan hoe, slice bar, and such other tools as are needed for the proper manipulation of a fire.

It is the duty of the roundhouse men to see that the sand-box is filled with clean, dry sand, but it is well enough for the fireman to have an eye to that also.

For the beginner, especiallly, there are a great many details to be learned, and he should get in touch with the engineer as soon as possible and keep in touch with him. In fact, the engineer and fireman should always work together, and strive to be of mutual help to each other in every possible way.

After getting the engine out of the roundhouse and before starting to take her around to the train, he should note carefully that all the switches that he will pass are properly lined up and that the track is clear. The engine bell should always be rung before starting, and be kept ringing while the engine is moving through the yards. Before starting from a terminal station the fireman should carefully prepare his fire—see that it is burning brightly and that it is heavy enough to prevent the exhaust from pulling it out of the fire-box when starting out. The depth of fire that should be carried on the grate bars depends upon the kind of fuel to be used. If soft coal is the fuel, a fire ten to twelve inches deep should be carried. If hard coal is used, the fire should not be so deep.

When the engine has been backed on to the train and it is about leaving time, the fireman should have his fire built up so that the coal will be burning in good shape with the upper layer in the form of coke, having an even amount spread over the grate surface and of sufficient thickness to insure the starting and pulling out of the train without injuring the fire while the engine is being worked at long cutoff.

Before leaving a terminal the fireman should carefully read the train orders and be certain that he understands them thoroughly. Out on the road he should use his eyes in watching the steam gauge and water glass, also try to familiarize himself with the grades and hills. Some engines steam better with the fire a little deeper along the sides and in the corners of the fire-box, allowing the center of the fire to be more shallow. If there is a brick arch or a water table in the fire-box, care should be taken that plenty of space be maintained between it and the fire. At the beginning of the run the fire is clean, and may be kept a little deeper without danger of clogging.

After starting out it is advisable to move the grates a little, not enough to let any fire through, but enough to loosen any clinkers or partially burned coal that may be on the grates that would prevent a free flow of air through the same. The fire should not be allowed to become thin enough to admit too much cold air to the fire-box, thereby cooling the fire-box below the igniting point and allowing the gases, that go to make up a good part of the fuel, to pass off unconsumed in the form of black smoke.

While the engineer is pulling out of a station and working her up to speed, the fireman should watch his fire closely and keep adding a good supply of coal, as there is danger of the fire being broken by the sharp, heavy exhaust. After a good rate of speed has been attained and the engineer has hooked his reverse lever back, the coal should be added to the fire often and in small quantities at a time, two scoopsfull at each fire being sufficient, always waiting until the black smoke emitted from the stack disappears or at least changes to a light gray color before throwing in a fresh fire, and then placing the coal in the brightest spots. If the train is light, one shovelful at a fire is enough. No set of rules for firing can be laid down that will apply to all conditions. The best rule, especially for a man new in the service, is to always be ready to receive suggestions from the engineer, who has passed through all the various phases of a fireman's apprenticeship and knows, or at least ought to know, his engine thoroughly and how to get the best service out of her. Therefore the fireman should always work under the instructions of the engineer; in fact, never do anything while on duty without first knowing that it would meet with his approval.

Care should be exercised in the regulation of the ash pan dampers for admitting air under the grates. The fireman should study closely the requirements of his fire in this respect. If too small a volume of air is admitted the fire will not burn as lively as it should, and if too much air enters the fire-box the gases will be chilled. Keep the ash pan clean and the grates will last longer.

As a general rule the fire will burn the heaviest in the four corners of the fire-box, along the sides and directly in under the flue sheet, this being caused by the vacuum which forms the draft being the heaviest nearest a solid body; in this case the sheets which form the fire-box defining its course.

The one shovelful plan gives good results, swinging or shutting the fire-box door between shovelsfull, and spacing the time between shovelsfull, so that the fire is kept at about the same degree of heat all the time.

The fireman should learn the lay of the road over which he is firing and fire according to the grades, know when to let the fire burn down for a meeting or passing point, if they have to take siding, and where to prepare for the bottom and summit of a hill and know how the engineer is going to work the engine at these places.

There are other things to be considered in the making of steam besides the handling of the coal; the water must be fed to the boiler in the same proportion as it is being evaporated into steam and kept at about the same level in the boiler.

If the boiler has a tendency to foam and work wet steam down through the cylinders, the water level in the boiler should be kept down to the lowest possible point consistent with safety, and the steam pressure reduced and the utmost care exercised in firing to keep the safety valve from popping, as this would raise the water and carry it over into the cylinders.

As the exhaust is the life breath of the locomotive, it might be well at this point to explain why it creates such a tremendous draft. The reason is, because of the volume and velocity of the steam as it issues from the exhaust nozzles. The air and gases in the stack are carried out or forced out of the stack by the exhaust, and this creates a partial vacuum in the smoke arch, into which the air and gases pass from the fire-box through the flues. Fresh air is also being forced into the fire-box through the grates and other apertures by the atmospheric pressure. The blower operates upon the same principle, although on a much smaller scale. It may be used to urge the fire when the engine is not working steam. The blower should also be used while cleaning the fire; it will clear the dust and ashes from the flues. If the engine is pulling a passenger train and the engineer is about to make a stop at a station, the fireman should, as soon as the throttle is closed, put on the blower lightly and open the fire door one-half inch, just sufficiently to allow a small volume of air to enter the fire-box above the fire. This will prevent the engine from throwing out a great volume of dense black smoke while making the stop.

With hard coal the proper thickness depends very much upon the size and the quality of the coal to be used. The larger the lumps the thicker the fire must be carried, as otherwise the large openings between the lumps would permit the air to rush in in such great volumes as to make it impossible to keep up steam, besides chilling the sheets and flues. In fact, if the fire was allowed to become too thin, the cold air would kill it. In firing hard coal care must constantly be exercised to keep the grates near the sheets or walls of the fire-box well covered, so as to prevent large air passages through the grates, as the admission of too much cold air will reduce the temperature of the fire-box below the igniting point of the coal. The secret of success as a hard coal fireman is to watch for and prevent the formation of spots through which large quantities of air can pass. This should apply to both freight and passenger service.

In firing soft coal, one of the most important points to be remembered is, to shake the grates sufficiently often to prevent them from becoming choked with clinker.

Almost all engines are provided with shaking grates. If these are used properly much of the trouble experienced due to dirty flues will be done away with.

Some firemen do not think of shaking the grates till the fire gets dirty; these men should remember that the grates should be shaken often enough to *keep the fire clean.* Move the lever with short, quick jerks to loosen up the fire and break up any clinker that may have begun to form.

Spreading the coal evenly when firing does not affect the even distribution of the air to the fire, but banking the fire certainly does change the draft as much as a change in the front end would.

Firing the coal in big lumps, instead of breaking it up to small size, has a similar effect to banking the fire at any point.

One other important point where the firing affects the draft is in the way the door is swung.

Many firemen, who are not in the habit of swinging the door shut after each scoopfull of coal is fired, do not believe that there is any use in doing so. When the door is open the draft pulls the air through the door instead of through the fire, or, in other words, while the door is open, the fire stops burning because there is no air coming through it. During this time that the cutting action of the draft through the fire is stopped any clinker-forming matter present will have a chance to run together, and a small clinker means a larger one in a short while. Besides this, the cold air coming through the door lowers the fire-box temperature, so that the gases do not burn, and this same cold air often starts flues to leaking.

The proper way to do is to swing the door shut after each scoopfull of coal is fired, and the good results obtained by doing this will more than pay for the little extra trouble

REGULATING THE DRAFT.

There is a direct passage of air through a locomotive from the atmosphere through the ash pan, grates, fire and fire-box, through the flues and front end and out of the stack. Exhaust steam from the cylinders passes through the exhaust passages in the saddle, through exhaust stand and nozzle and out the stack, the front end being so arranged that the exhaust will form a jet and will enter the stack somewhere near its base. This exhaust steam passing at high velocity through the front end and out the stack has a tendency to carry with it the air and gas in the front end in a manner somewhat similar to a train at high speed picking up dust and papers and carrying them along.

This emptying of the front end of air and gas simply means that the passage of exhaust steam from cylinder to stack reduces the front end pressure below atmospheric pressure, or, in other words, creates a vacuum in the front end. Whenever there is less pressure in the front end than there is outdoors the air from outdoors is going to try to get in the front end. If the front end is tight, the only place air can enter to it while the engine is working steam is through the ash pan, grates, fire, fire-box and flues, creating a current of air through the fire-box and fire and producing the artificial, or forced draft, of locomotives.

The draft produced by a blower is somewhat similar to that produced by the exhaust steam. The pipe from the blower extends into the front end to a point directly under the stack, and its end turns up so that when steam passes through it the jet will pass up through the stack.

In order to get proper combustion of fuel the draft must be even all through the fire and strong enough to give the proper air supply for the burning. To accomplish this, certain draft appliances are arranged in the front end, and these must be properly adjusted to give best results. The exhaust stand and nozzle must be placed central and in line with the stack, so that the exhaust jet will be properly directed. If the exhaust nozzle is low a petticoat pipe is placed between it and the stack, to keep the exhaust jet from spreading outside of the base of the stack. Sometimes the petticoat pipe is left out and a flare made at the base of the stack, which serves the same purpose.

The action of the draft on the fire in most instances is so strong that sparks are carried with the gases and products of combustion into the front end. In order that these sparks may be broken up and cooled off before being thrown out of the stack, a deflector plate (sometimes called a draft sheet or diaphragm) extends outward a few inches from the front flue sheet above the level of the flues, and then turns down at a sharp slope, the bottom edge coming near enough to the bottom of the front end to cause the sparks to be carried well forward. A netting is fitted in the front end to prevent any sparks passing out of the stack unless they first pass through the netting. The mesh of the netting is small enough so that the danger of sparks starting fires is practically done away with.

The majority of roads today use a front end patterned after the Master Mechanic's standard, *i. e.,* one having a deflector and a petticoat pipe. With such a front end the draft through the flues is regulated mainly by the position of the deflector plate; the force or intensity of the draft is regulated by the size of the nozzle and the position of the petticoat pipe.

In order to have an even burning fire the draft through the flues should be equal. This even pull through the flues can be gotten by adjusting the movable slide on the bottom of the deflector plate up or down, as the case indicates. If the fire burns too fast near the flue sheet the draft through the bottom flues is too strong and the plate should be raised. If the fire burns too fast near the door the draft through the upper flues is too strong and the plate should be lowered to equalize the draft through the flues.

The supply of air to the fire is governed by the intensity of the draft.

The exhaust jet must fill the stack near the base, otherwise the draft will be seriously interfered with.

The petticoat pipe is placed so that the opening between the nozzle and the bottom of the pipe is about the same as that between the top of the pipe and the base of the stack.

Speaking generally, if the petticoat pipe is properly placed, an increase in the size of the nozzle reduces the intensity of the draft, and a reduction in the size of the nozzle increases the intensity of the draft.

It must be remembered that a small nozzle increases the back pressure in the cylinders and reduces the power of the engine.

A bridge in the nozzle has a tendency to spread the exhaust jet and fill the stack better, giving a better draft in some cases, especially on an engine having a large stack and a high nozzle. When a bridge is used the opening of the nozzle should be increased enough to make up for the size of the bridge.

Raising and lowering the sleeve of the petticoat pipe affects the force of the draft, and in some engines where the deflector is high affects the even burning of the fire. If the sleeve is too high the draft is reduced, and in some cases the fire burns too fast near the flue sheet. If the sleeve is too low the draft is also reduced, and in some cases the fire burns too fast near the door.

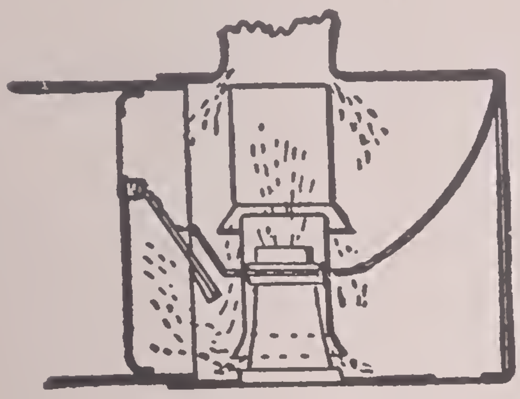


Fig. 1.

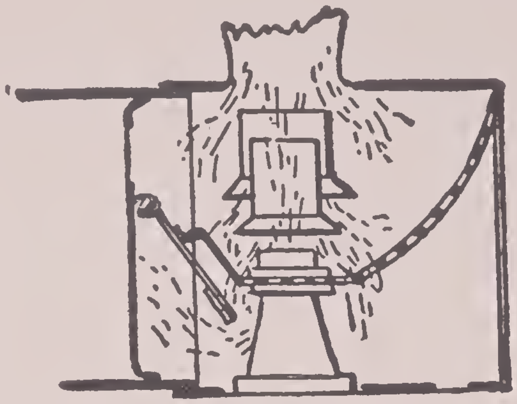


Fig. 2.

Figs. 1 and 2 show the petticoat pipe and sleeve in two different positions. Fig. 1 shows the pipe and sleeve extended in such a manner as to nearly cover the distance between the base of the stack, and the base of the exhaust pipe, thus reducing the opening for the exhaust steam to a very small area, as shown by the dotted lines which represent its path.

Fig. 2 shows the pipe raised above the exhaust nozzle tip, and the sleeve lowered away from the base of the stack, thus allowing a much freer exhaust. The one position tends to decrease the draft, the other to increase it and the point of adjustment that will produce the most satisfactory results can only be ascertained by careful and judicious experimenting.

In fact, the nozzle, petticoat pipe, sleeve and stack may be considered as acting somewhat on the principle of an injector on a large scale and adjustments be made accordingly.

The exhaust pipes or nozzles are made of cast iron. Sometimes a single nozzle is used, such as shown in section in Fig. 3, having a partition at its base. In other cases two nozzles are used, which are generally cast together, as shown in section in Fig. 4.

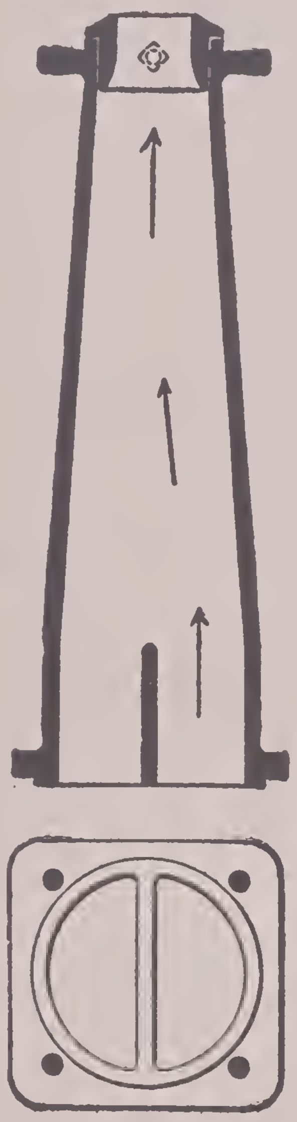


Fig. 3.

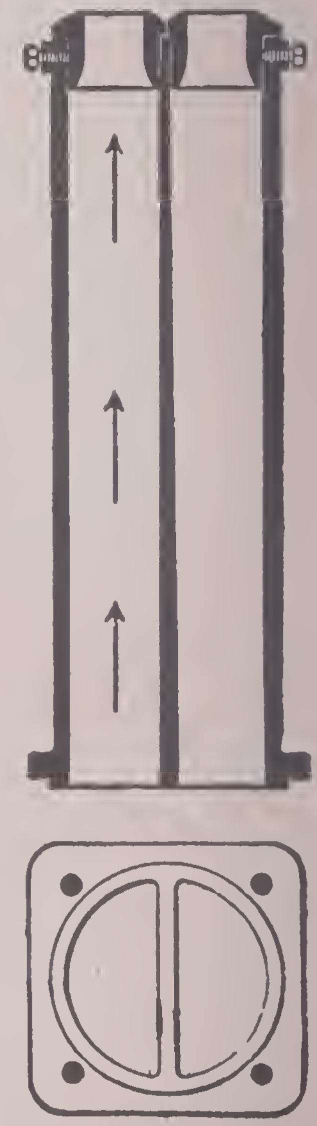


Fig. 4.

Fig. 5 is a plan view of single and double nozzles. Rings or bushings are fitted in the outlet openings of these nozzles for the purpose of reducing their area and thereby increasing the draft. These bushings are made of various diameters and are easily removed in order to substitute others with larger or smaller openings as they may be required. If the exhaust orifice is too large the draft through the tubes will not be sufficient. On the other hand, if the area of the exhaust opening is reduced too much the back pressure in the cylinders will be increased, thereby limiting the power of the engine. It is therefore necessary that great care and good judgment be exercised in the adjustment of the exhaust nozzles.

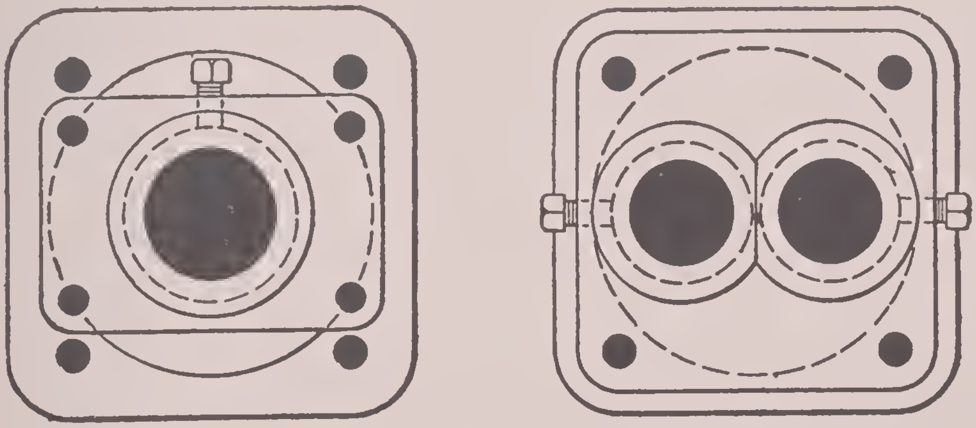


Fig. 5.

Various devices have been invented for adjusting the area of the exhaust nozzles while the engine is working steam, but none has proved to be satisfactory, and the old method of adjustment when the engine is not working is still in vogue. A few of the many devices that have been invented for regulating the draft will be described in this connection.

Fig. 6 shows a form of adjustable nozzle that appears to have considerable merit. It is the invention of Messrs.

Wallace and Kellog, two engineers on the St. P., M. & O. R. R., and it has been used to some extent on that road, also on the Duluth & Iron Range R. R. The device is automatic in its operation, the regulating mechanism being connected to the reverse lever, or the reach rod, in such a manner that as the lever is moved from the center notch towards either corner the area of the nozzle is increased one-half square inch for each notch. It may be set so that with the reverse lever in either corner there will be seven square inches more of nozzle area than there is with the lever in or near the center notch.

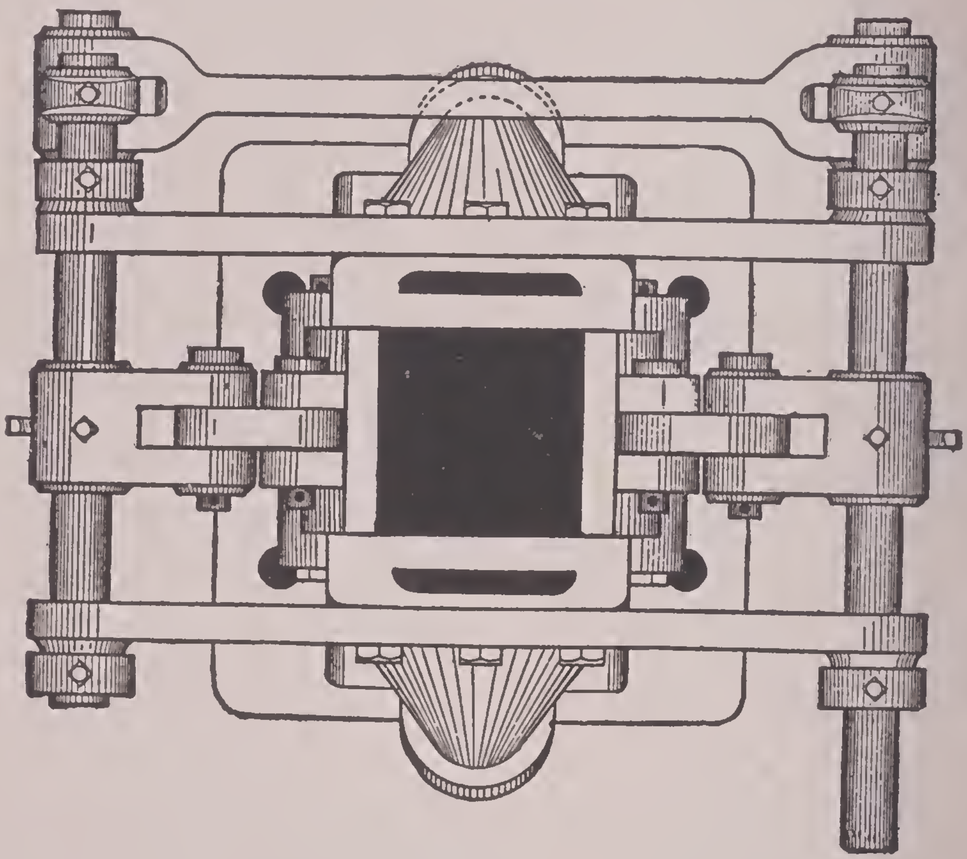


Fig. 6.

The nozzle areas for different positions of the reverse lever are as follows: Center notch, 22 sq. in.; second notch, 23 sq. in.; fourth notch, 24⅜ sq. in.; sixth notch, 25½ sq. in.; eighth notch, 26 9-16 sq. in.; tenth notch, 28½ sq. in., and in the corner, 29 11-16 sq. in. The device is said to work satisfactorily and has shown a saving in fuel of from $59.00 to $97.00 per month over the ordinary nozzle.

Fig. 6 shows a plan and Fig. 7 an elevation, the cuts being self-explanatory.

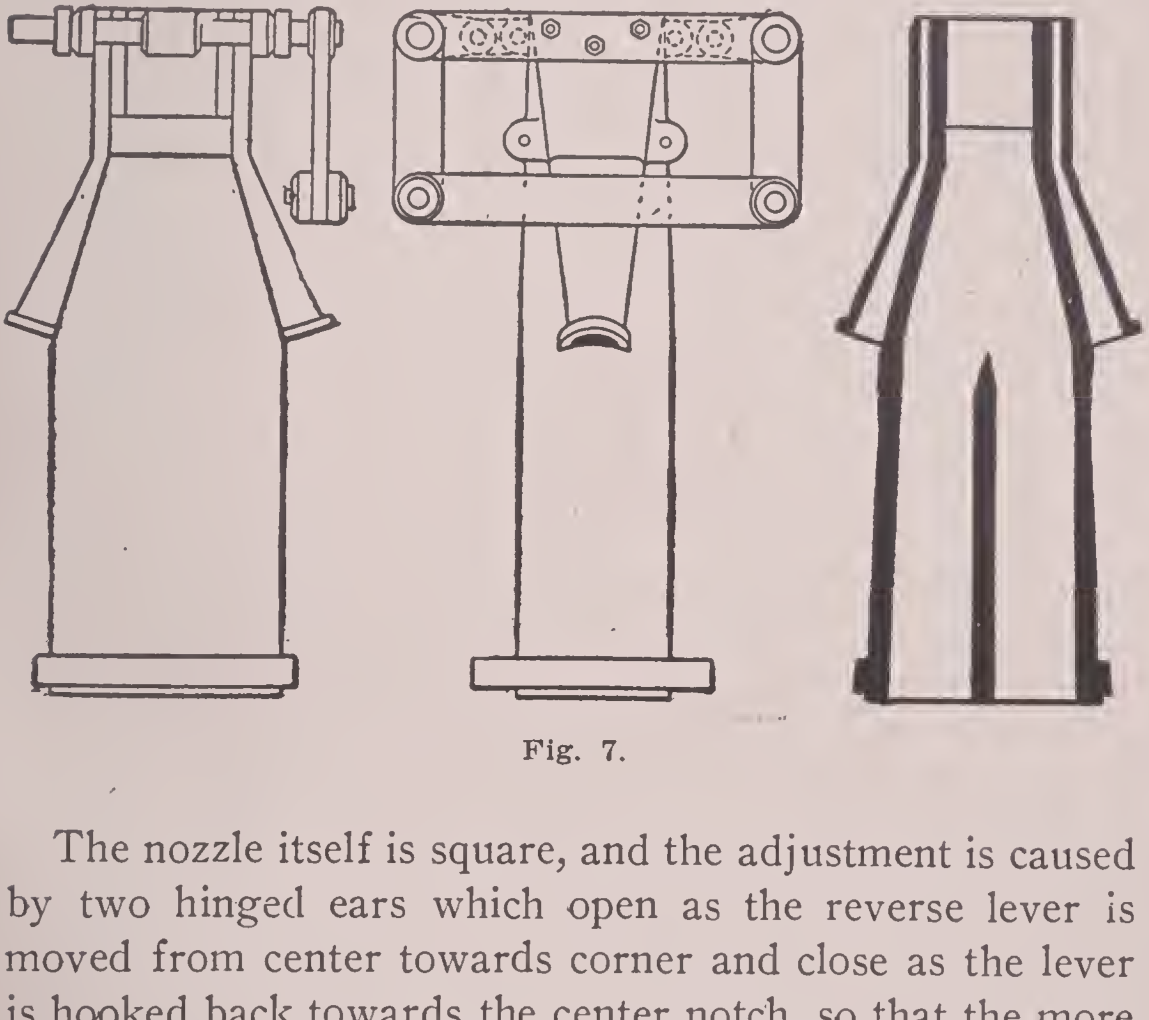


Fig. 7.

The nozzle itself is square, and the adjustment is caused by two hinged ears which open as the reverse lever is moved from center towards corner and close as the lever is hooked back towards the center notch, so that the more steam that is being used the larger will be the nozzle area, and *vice versa.*

The De Lancey Exhaust Nozzle.—This is another form of variable exhaust nozzle, as may be seen by the illustrations. It is the invention of Mr. John J. De

Lancey, of Binghamton, N. Y., who describes his device in the following words:

"The object of my invention is to provide a new and improved exhaust nozzle for locomotives, serving to regulate the exhaust of the engines, and thereby regulating the draft in the boiler.

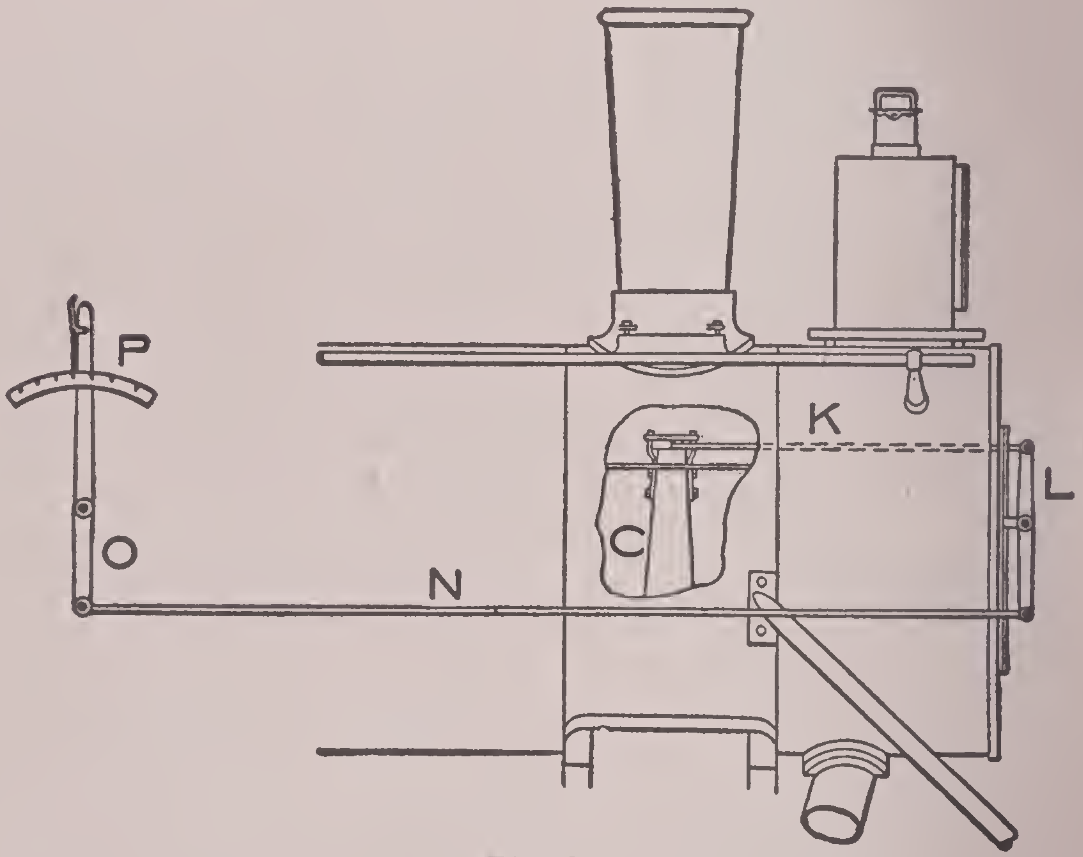


Fig. 8.

"Fig. 8 is a side elevation of the improvement as applied to a locomotive, parts being broken out. Fig 9 is an enlarged plan view of the improvement. Fig. 10 is a transverse vertical section of the same. Fig. 11 is a sectional side elevation of the same on the line *x x* of Fig. 9, and Fig. 12 is a plan view of a modified form of the plate

"The improved exhaust nozzle is provided with a plate B, fitted onto the upper end of the exhaust pipe C, which may be double, as is illustrated in Fig. 10, or single—that is, the two exhausts of the engines of the locomotive running into a single exhaust pipe.

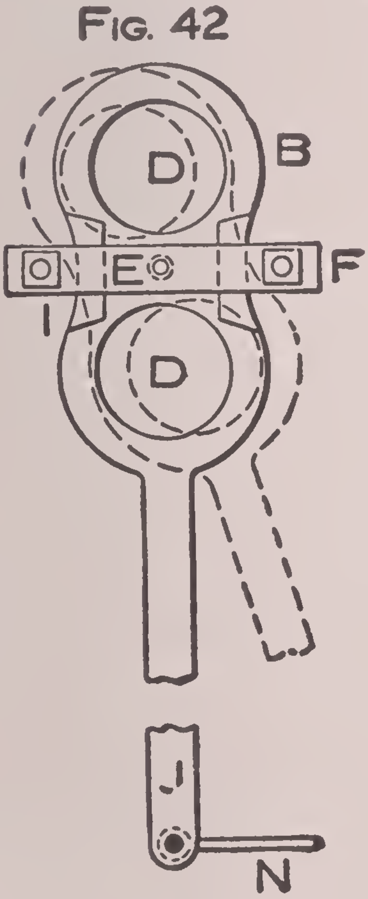


Fig. 9.

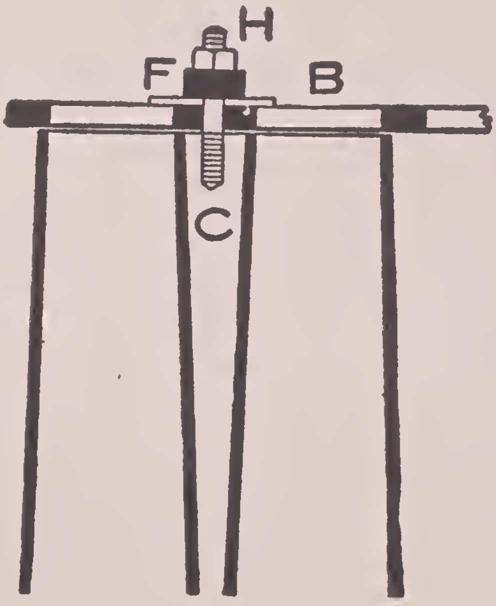


Fig. 10.

"The plate B is provided with apertures D of the same size as the apertures at the upper ends of the exhaust pipe C, so that when the plate B is in a central or normal position the apertures D of the plate B fully register with the openings in the end of the exhaust nozzle. The plate B is fulcrumed in its middle on a pin E, projecting from a bar F, supported on brackets G, secured to the sides of the exhaust pipe C, the said plate being held in place on the brackets by nuts H, screwing on the threaded ends of the said brackets G, as is plainly illustrated in Fig. 11. The pin E, after passing through the plate B, also passes a short distance into the top of the exhaust pipe C, so as to form a secure bearing for the plate B. On the top of the latter, at its sides in the middle, are arranged offsets I, onto which fits the under side of part of the bar F in such a manner that the plate B is free to turn on its pivot E, and at the same time is held securely against the upper end of the exhaust pipe C to prevent the plate from being lifted upward by the force of the exhaust steam.

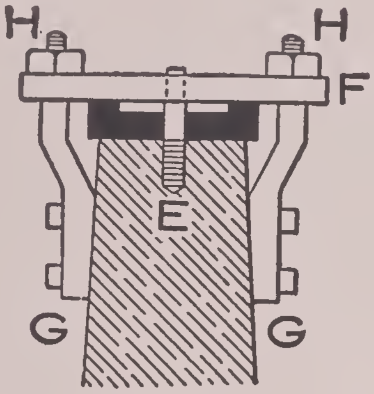


Fig. 11.

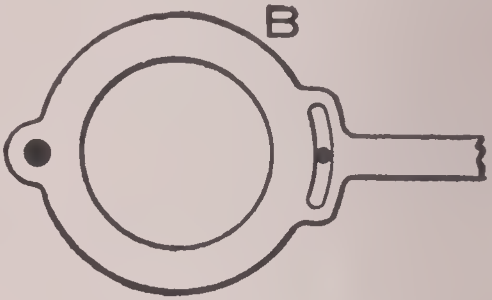


Fig. 12.

"From the plate B projects to one side an arm J, pivotally connected by a link K with a lever L, fulcrumed on the outside at the front end of the locomotive boiler, the link K passing through the said front end. The lever L is also pivotally connected by a link N, extending along the outside of the locomotive, with a lever O, pivoted on the cab of the locomotive and extending into the same so as to be within convenient reach of the engineer in charge of the locomotive. The lever O is adapted to be locked in place in any desired position by the usual arrangement connected with a notched segment P, as shown in Fig. 8.

"When the lever O stands in a vertical position, as illustrated in the said figure, the openings D in the plate B fully register with the openings in the exhaust pipe C. In this position the exhaust steam can pass freely out of the exhaust pipe C through the smoke-box and smokestack of the locomotive, so as to cause considerable draft in the fire-box of the boiler. When it is desirable to increase the amount of draft in the fire-box of the locomotive, the engineer in charge of the locomotive operates the lever O either forward or backward, so that the lever L swings and imparts a swinging motion by the link K and the arm J to the plate B, which latter moves across the top of the exhaust pipe C, and part of the openings of the latter are cut off or diminished in size, so that the exhaust of the engine is retarded, and consequently the draft in the smoke-box and smokestack is increased, so that a consequent increase of the draft takes place in the fire-box of the locomotive.

"It will be seen that the two openings in the exhaust pipe are diminished in size alike by moving the plate B, and it is immaterial in which direction the engineer moves the lever O, as the cut-off takes place either way."

Canby Draft Regulator.—Fig. 13 shows the Canby draft regulating apparatus, invented by Mr. Joseph C. Canby of Orange, Luzerne Co., Pa., and the following description of the device is furnished by the inventor himself:

"My invention relates to draft-regulating apparatus for locomotive and that class of boilers; and it consists of a smokestack with an adjustable petticoat or mouthpiece to equalize the draft through all the flues, also an arrangement of pipes and valves to introduce fresh air into the smokestack to check the draft without opening the fire door and letting the cold air in onto the boiler and tubes, thereby making a great saving in the fuel and being better for the boiler and flues."

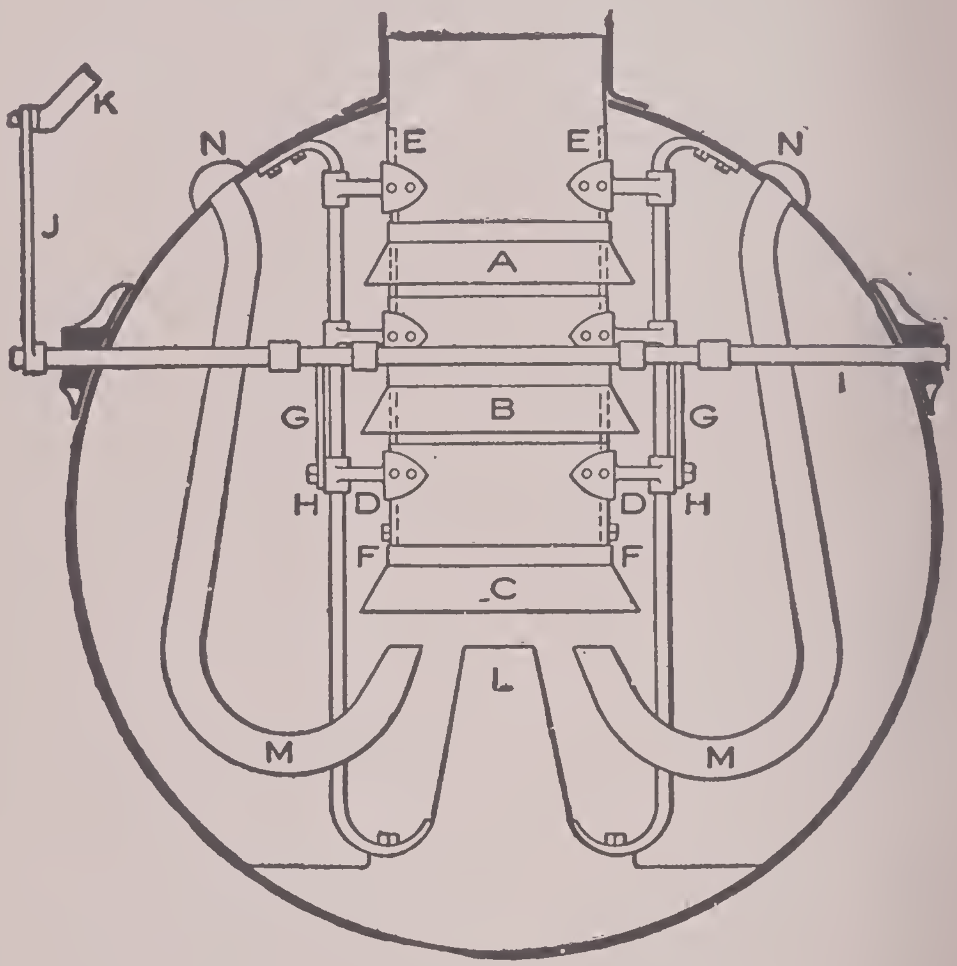


Fig. 13.

Fig. 13 represents the front view of the boiler with the automatic draft regulator attached. Fig. 14 is a horizontal section of front of boiler, showing smokestack and rock shaft. Fig. 15 is a longitudinal section of the smoke-box and boiler, showing the connection of the valve N and regulator O and the connection of arm J to the cab K by the rod R.

A B C represent the sections of the smokestack, or, as familiarly called, "petticoats," arranged with lugs D on the sides with slides E E, having slots and set screws F F, by which they are adjusted to the space required between them, thereby enabling the engineer to equalize the draft in the fire-box, as experience shows that when the draft is nearest to the bottom of the smoke jacket the draft is strongest on the back end of the fire next the flue, and by decreasing there and increasing it in the top flues the draft is made stronger in the front part of the fire-box. This more nearly equalizes the combustion of the fuel. The connecting rods G G are attached to the lugs H, and the arms S S project from the rocking shaft I, which is operated by the arm J and rod K, which runs to the cab R. By pulling or pushing the rod K the petticoats are raised and lowered, thus increasing and decreasing the distance from the exhaust nozzle L, thereby increasing or diminishing the draft. The air tubes M M turn up alongside the exhaust nozzle L, and

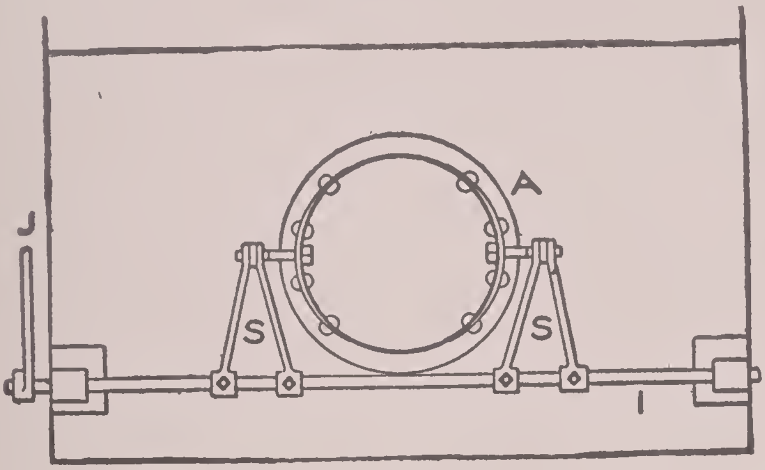


Fig. 14.

are opened and closed by valves N N on the outside of the boiler. The valves are operated by a pressure regulator O, so adjusted that they are opened by the steam when it passes a given pressure. This operates on the crank P and connecting rod Q to open the valve, thus admitting air to the smoke-box and decreasing the amount drawn through the tubes and decreasing the consumption of the coal, and obtaining the full benefit of all fuel consumed without letting the cold air in onto the hot iron. By this means we have the combustion automatically regulated, also obtaining the greatest amount of heat from the fuel consumed.

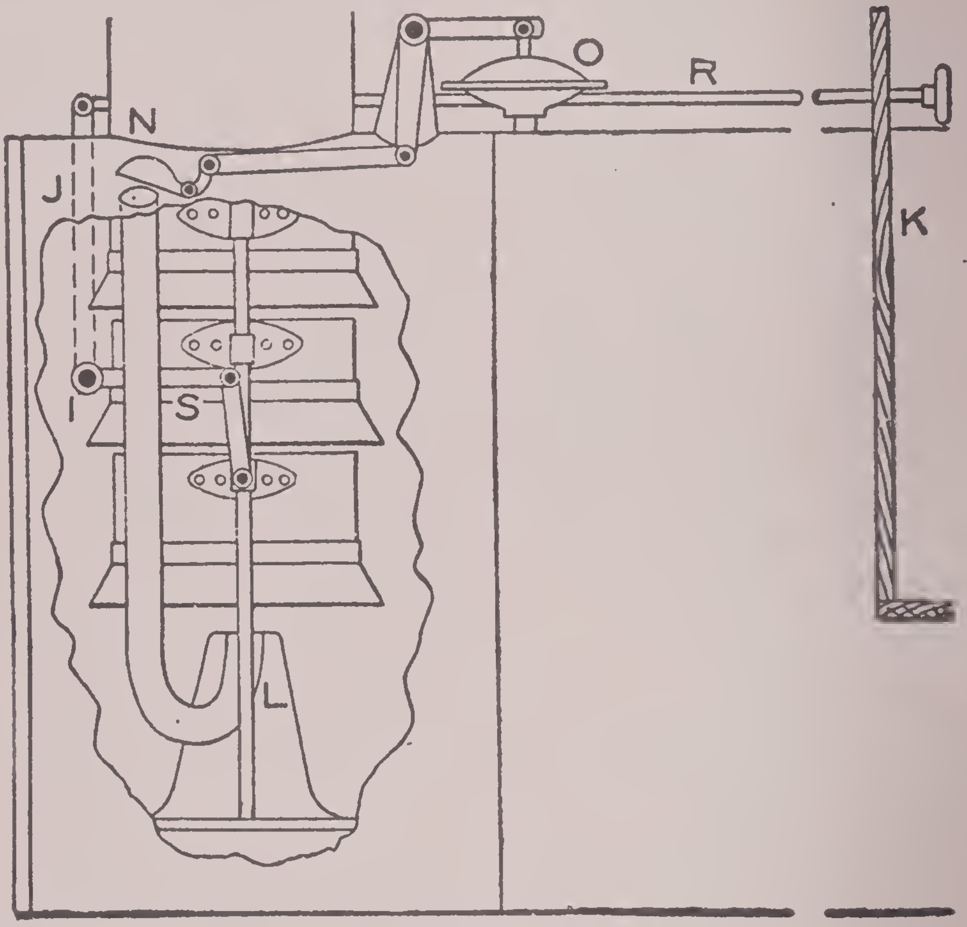


Fig. 15.

The petticoat or draft pipe is a very important factor in the regulation of the draft in a locomotive, so as to have the fire burn equally in all parts of the fire-box. Sometimes the fire is inclined to burn the strongest at the back end of the fire-box. This is caused by the draught pipe being set too low. On the other hand, if the fire burns the strongest at the front it shows that the petticoat pipe is too high and it should be lowered.

The exhaust nozzles become at times coated with a hard, gummy substance on the inside, thus decreasing their area, and the result of this is that the fire is torn and cut to pieces on account of the too strong draft. The remedy for this is to ream out the nozzles by means of a reamer having a long handle whereby it can be introduced through the stack.

Another device for regulating the draft is used in the extended smoke-box. This is a diaphragm placed at an angle of 20 degrees usually, although some high authorities advocate placing it at 30 degrees. The gases impinge against the diaphragm, and are thus impeded in their passage to the stack, the flow being regulated by means of a diaphragm damper.

One very important requisite for obtaining good combustion and an even burning fire in a locomotive is that the exhaust should fill the stack, and not go through it like a shot out of a cannon, chopping the fire and carrying with it green coal and a large volume of gases that are unconsumed. Close observation and careful work are needed to guard against the great waste of fuel caused by an incorrect adjustment of the various factors contained within the smoke-box or front end.

The raising of the apron or damper on the diaphragm will give more draft through the top flues and cause the fire to burn more brightly at the back of the fire-box, and to lower the apron causes a stronger draft through the lower tubes and a consequent harder burning of the fire at the front. In experimenting along this line, a change of a quarter of an inch at a time is sufficient until the proper position for the apron is found.

The following timely observations on the locomotive front end are from the pen of Mr. K. P. Alexander, master mechanic of the Ft. S. and W. R. R., and were published in the May, June and July, 1905, issues of Railway and Locomotive Engineering. By permission of Mr. Angus Sinclair, editor of that valuable journal, the article is here inserted.

"For much of the data used in this paper I take pleasure in acknowledging indebtedness to Prof. W. F. M. Goss of Purdue University, and committee reports of the American Railway Master Mechanics' Association for blue prints, reports, personal information, etc. Without presuming to give as much detailed information, this article is intended to more completely embrace the known facts relating to the several parts of the front end than any single report that has appeared.

The "front end," Fig. 16, includes the diaphragm, the exhaust nozzle, the exhaust stand, the stack, the petticoat pipe, and the netting. These, with the exhaust jet, constitute an apparatus designed to produce the maximum amount of draft through the fire with the minimum of back pressure in the cylinders. The efficiency of the front end is therefore the greatest possible ratio of draft to back pressure.

THE DIAPHRAGM. The total draft is said to have three approximately equal factors of resistance to overcome: the diaphragm and netting, the flues, and the fire, grates

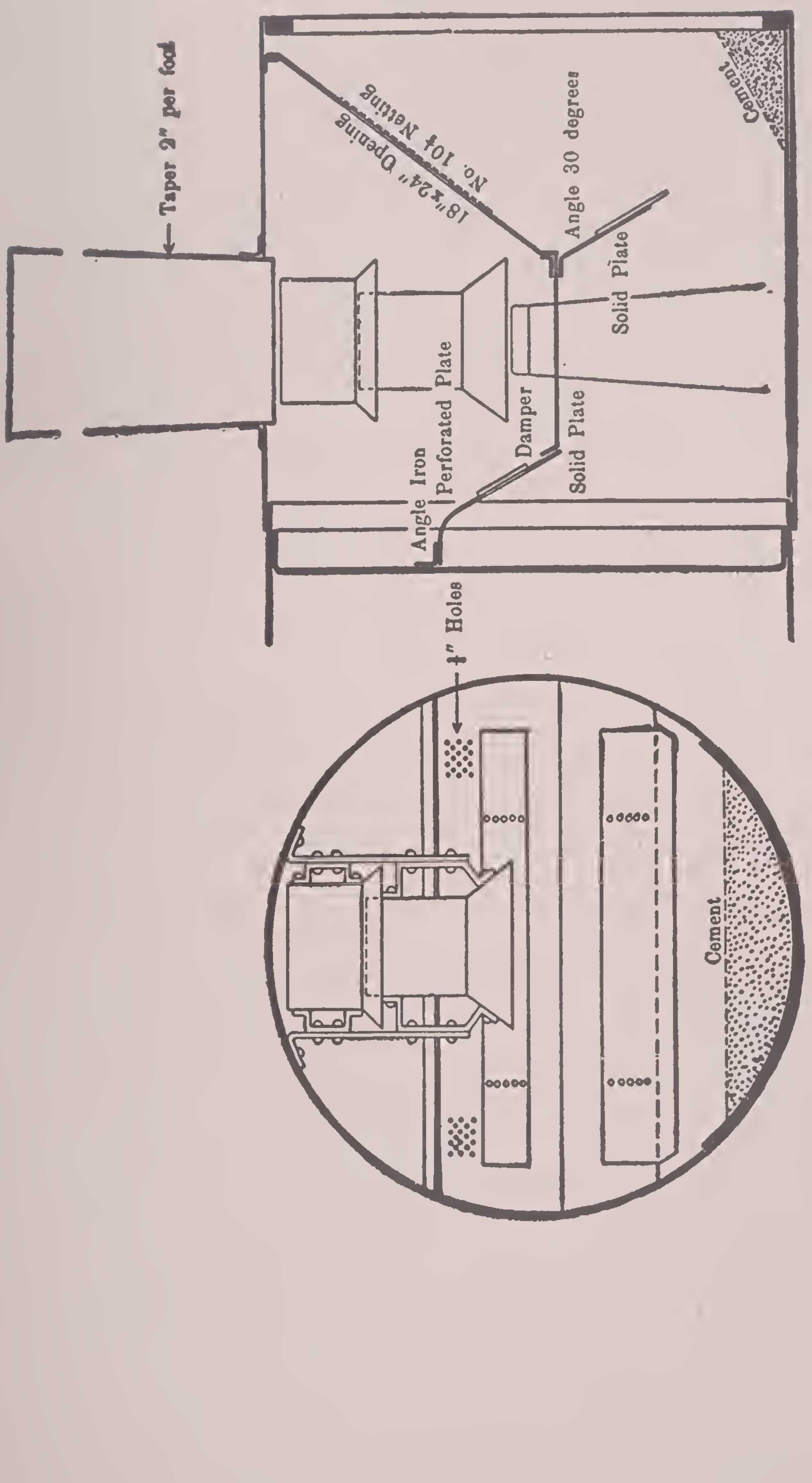


Fig. 16. The "Front End."

and ash pan. As the diaphragm (or baffle plate) absorbs about one-third of the energy of the exhaust jet, the net efficiency of the front end is evidently increased as the angle of the diaphragm is changed from the usual angle of 20 degrees toward a more horizontal position, or to an angle of probably 25 degrees. Within certain limitations the front end is also increased in efficiency by enlarging the area of the opening under the diaphragm damper. Indeed, it is said that there are foreign railroads that have in some manner successfully dispensed with the diaphragm and yet secured equalization of draft over the entire fire-box.

The opening under the diaphragm damper must however, be of such width horizontally as will allow of an area of opening equal to the total cross-sectional area of the opening through the flues, and at the same time be sufficiently contracted to retard the flow of gases from the fire-box long enough to consume as great a per cent of the gases as affecting conditions will permit. It must also be sufficiently contracted, in self-cleaning front ends, to obtain enough velocity to keep the front clean of sparks. The diaphragm damper, or movable deflecting plate, must be set at such height as, with a given angle of the diaphragm, will produce a slightly stronger draft at the back than at the front end of the fire-box. The area of opening under the diaphragm should be greater for slow-burning than for free-burning coal, as, by diminishing the non-effective work that must be performed by the exhaust jet, the nozzle may be enlarged or a greater per cent of its effective energy may be utilized in producing draft through the fire.

Draft through the fire in the back end of the fire-box is increased by increasing the angle of the diaphragm, or by raising the diaphragm damper, also by about four horizontal rows of holes punched in the upper end of the top section of the diaphragm. As the amount of draft is proportional to the weight of steam exhausted per unit of time, it is believed that differences in grate area do not materially change the volume of gases passing under the diaphragm. Contracted opening under the diaphragm, or through the grates, probably results in slight cylinder back pressure. When the area of opening under the diaphragm is enlarged by raising the diaphragm damper beyond a certain limit, the angle of the diaphragm must be decreased. The effect of wings projecting at each end of and below the diaphragm is to decrease the draft at the side sheets and to concentrate it along the center of the fire-box. The length of the horizontal part of the diaphragm (distance between the upper and lower sections) does not affect the draft in either end of the fire-box.

The most efficient diaphragm should give the following: Most rapid rate of combustion, slightly stronger draft at the back than at the front end of the fire-box, sufficiently baffle the flow of gases so as to result in the most complete combustion that the affecting conditions will allow, with minimum resistance to the exhaust jet.

Such a diaphragm should have an angle of about 25, instead of 20 degrees. Just below the arc of a 5-in. radius bend in the top end of the upper section should be punched about four horizontal rows of ⅜-in. holes with ⅜-in. centers, extending across the upper section a distance equal to the distance between the steam pipe centers at that height. An adjustable damper should be applied, to regulate the area of opening through the holes, in order that the proper degree of draft may be obtained in the back end of the fire-box. On the back side of both sections of the diaphragm should be bolted perforated steel plate with 3-16x1½ in. mesh, set with slots vertical.

The object in increasing the angle of the diaphragm from 20 degrees (the usual angle) to 25 degrees, is to diminish the resistance to the exhaust jet. But, with such a change in angle, the four rows of ⅜-in. holes in the upper section are necessary in order to increase the draft in the back end of the fire-box as much as the change of angle increased it in the front end of the fire-box. The perforated steel plate bolted to the back side of the diaphragm very materially assists in breaking up the cinders as they strike it at an angle, thus considerably increasing their facility in passing through the netting and decreasing the liability of starting fires. This is equivalent to increasing the netting area or enlarging the opening of the mesh, and therefore lessens the total amount of work that must be performed by the exhaust jet. The horizontal plate of the diaphragm should always, regardless of the height of the exhaust stand, for self-cleaning front ends, be located just under the top flange of the exhaust stand. In order to get in sufficient netting for free steaming this plate should never be set higher than 2 in. below the center line of the smoke-box, nor more than 6 in. below the top of the nozzle.

THE EXHAUST JET AND NOZZLE. The most accurate, reliable and comprehensive data on the form, density and efficiency of the exhaust jet, is contained in the 1896 report of a committee of the American Railway Master Mechanics' Association, under the chairmanship of Robert Quayle of the Chicago and Northwestern Ry. The matter in this paper referring to the exhaust jet, especially the measurements of vacuum and pressure in stack and front end, is largely based on that report.

The cross-sectional form of the exhaust jet is influenced by the form and dimensions of the channel surrounding it, even though not in actual contact. It is supposed that, in the stack, the vacuum around the column of the exhaust tends to compact it and thus prevent contact with the stack until it reaches nearly to the top of the stack. Whether it is true or not, personal experiments indicate that when the surrounding channel is within a certain distance of a column of steam issuing from a taper nozzle, the jet is apparently attracted to and comes in actual contact with the enclosing channel. Accurate tests made by the Master Mechanics' Association Committee show beyond question that the exhaust jet does not, and preferably should not, fill the stack at or near its base, but that it comes in contact with the stack only quite near the top. The foregoing facts should be remembered in connection with calculating the diameter of petticoat pipes. The plan of the angle of the exhaust jet is not like an inverted frustrum with sides of straight lines, as is commonly supposed. Its form, between the nozzle and its point of contact with the stack, is represented by two slightly concave curved lines. It is in actual contact with the stack only about 10 or 12 in.

Vacuum gauges (measured in inches of water) show that the vacuum between the wall of the stack and the column of the exhaust jet, at a point one-third of the length of the stack from its top, is 1.50, midway of its length it is 2.52, and at about 17 in. from its base it is 3.61. At a point midway between the smoke-box circumference and the nozzle, on a line with the center of the arch, the vacuum is 2.54.

The pressures in the center of the exhaust jet are, at about 12 in. above the nozzle, 59.3; 24 in. above the nozzle, 44.6, and about 6 in. below the top of the arch, 28.5. The gauge also showed that the pressure diminished rapidly as it was moved from the center toward the circumference of the jet, varying in velocity from 576 to 292 ft. per second. Increasing the number of pounds of steam exhausted per unit of time, or increasing the boiler pressure, increases the velocity and diminishes the spread of the jet, resulting in increasing the vacuum.

The direction of the gases in every part of the smoke-box and stack is from the nozzle tip up toward the exhaust jet, and not directly toward the stack. The smoke-box gases and sparks are slightly enfolded within, but largely entrained by the exhaust jet. The induced action of the jet is greatest and the intermixing or enfolding action least at the nozzle. It is believed that as the mixing action is increased the induced action is diminished, with no resulting gain, and that therefore the more compact the jet the higher will be its net efficiency.

It is claimed that the efficiency of the jet is unchanged, providing the weight of steam exhausted per unit of time is equal, whether the engine is working at long cut-off with heavy impulses of the exhaust at long intervals, or working at short cut-off with quicker or lighter impulses at shorter intervals. The nozzle diameter should be as great as affecting conditions will permit.

Increasing the rate of combustion by undue contraction of the nozzle or grate area results in considerable decrease in evaporation per pound of coal. This is due to back pressure in the cylinders and to excessive spark losses and incomplete combustion of the gases in the firebox. Increasing the rate of combustion per square foot of grate surface per hour from 61.4 to 240.8 lbs., decreased the evaporative efficiency 19.2 per cent and increased the pounds of sparks per hour from 46 to 160 lbs.

There is doubt as to whether a splitter or bridge in the nozzle is of any benefit under any possible conditions. However, apparently good results have been obtained by enlarging a nozzle equal to the cross-sectional area of a ¼-in. or ⅜-in. splitter, when such splitter was placed in the top of the nozzle at right angle to the partition in the exhaust stand. Any possible advantage of such a bridge would be its effectiveness in overcoming the form of the exhaust (in an exaggerated form represented by the shape of a figure 8) due to the action of the exhaust jet in exhausting somewhat from side to side instead of exactly vertical, this being due to the deflecting influence of the exhaust stand partition and the inner angle of the nozzle.

The most efficient form of exhaust nozzle is the single one, with its interior in the form of a frustrum of a cone, ending at the top end with a parallel cylinder 2 in. long. The distance from the nozzle to choke of 14-in. stack 52 in. long, on a 58-in. front end, should not exceed 50 in. or be less than 40 in., for maximum efficiency. The distance from nozzle to top of smoke arch with a 14-in. straight stack 52 in. long should not be less than 22 in. nor greater than 38 in. The distance from nozzle to top of arch with a 16-in. straight stack 52 in. long should not be less than 28 in. nor greater than 38 in. The distance between nozzle and choke of stack should be slightly increased for the highest steam pressure.

The Exhaust Stand. The cross-sectional area of choke in each side of exhaust stands (when choked at all) should at least equal the area of the largest nozzle that may be applied. Bulged, or pear-shaped, stands are objectionable on account of interfering with the free passage of gases from under the diaphragm damper. Stands should be not less than 19 in. high. They should have a partition in them to prevent the exhaust from one side effecting back pressure in the other side of the engine, but such partition should not be less than 8 in. nor more than 12 in. high, and it should not extend a greater height than to a point 10 in. from the top of the stand.

The Stack. For a 54-in. front end, the highest efficiency is obtained by a tapered stack, tapered 2 in. per foot, with its smallest diameter a distance of 17½ in. from its base. The greater the height of stack the greater will be its efficiency. Tapered stacks whether long or short, should equal in diameter at inside of choke one-fourth of the diameter of the arch. The diameter of the stack should be diminished as the nozzle is raised.

Professor Goss gives the following formula for determing correct nozzle heights. H equals height of stack, h equals distance in inches between center line of boiler and nozzle, d equals diameter of choke of stack, and D equals diameter of front end.

Formula for Tapered Stacks. When nozzle is below center line of boiler: $d=.25\ D+.16h$. When nozzle is above center line of boiler: $d=.25\ D-.16h$. When nozzle is on center line of boiler: $d=.25\ D$.

Formula for Straight Stacks. When nozzle is below center line of boiler: $d=(.246+.00123\ H)\ D+.19\ h$. When nozzle is above center line of boiler: $d=(.246+.00123\ H)\ D-.19\ h$.

THE PETTICOAT PIPE. As a means of increasing the induced action of the exhaust jet, rather than as a means of equalizing front and back the draft on the fire, double petticoat (or draft) pipes add to the efficiency of the front end. When the distance between the nozzle and the choke of the stack (the top of the arch, with a straight stack) is not great enough to make a double pipe practicable, a single pipe is beneficial. The efficiency of the draft pipe is mainly due to its forming a longer orifice through which the exhaust must pass, thereby augmenting the induced action of the exhaust jet by solidifying it, it not being essential or desirable that the jet come in actual contact with the draft pipe. In fact, the pipe should be so large that the jet will not touch it.

In a 58-in. front end the best results were obtained with a 14-in. choke stack, choke 12 in. above top of arch, nozzle 45 in. from choke, with a double petticoat pipe. The highest net efficiency was when the bottom end was set even with (but none below) the top of the nozzle. The top end of the upper section was set 13½ in. below the choke of the stack. The total distance from nozzle to top of upper section, in this position, was 28½ in. The smoke-box vacuum decreased as the distance was lengthened to 31 in., and the back pressure in the cylinders increased as the distance was shortened from 29 to 28 in. The double petticoat pipe used in above test was of the following dimensions: lower section, 10 in. diameter by 11 in. long; upper section, 13 in. diameter by 10 in. long. The flare on lower section was 7 in. high by 17¼ in. diameter at bottom; flare on upper section was 2 in. high by 15 in. diameter at bottom end.

THE NETTING. No data is on record of the amount of resistance to the exhaust jet due to the front end netting, or perforated steel plate. The total area of netting should be as great, and its mesh as large, as conditions will, with safety, permit; as the open area is considerably reduced at each impulse of the exhaust by sparks in process of being broken up sufficiently small to pass through. As the direction of the sparks in the smoke box is from every point toward the column of the exhaust jet, instead of directly toward the stack, the netting should be set so that, as nearly as may be, the sparks will strike it at right angle to its face.

Although some railroads use coarser and some finer mesh, it is probable that the most preferable is netting with 2½×2½ mesh No. 10½ double crimped steel wire or 3-16×1½ in. perforated steel plate, with the plate set so that the slots run vertically instead of horizontally. The chief objection to the perforated steel plate is that it necessarily contains less open area in proportion to its closed area than netting. A point in its favor, however, is that sparks cannot as easily wedge in the perforations as in the mesh of the netting.

THE SMITH TRIPLE EXPANSION EXHAUST PIPE.

This device is the invention of Mr. John Y. Smith, the originator of the Smith vacuum brake. In the cuts of the front and side views shown in Fig. 17, *A A* represent air passages, *S S* exhaust steam passages, and *B* an annular blower, forming part of the nozzle. This is an entirely new departure in the construction of exhaust pipes for locomotives. Its distinguishing features are that the exhaust steam is not restricted after it leaves the cylinders, and the gases and heated air in the smoke arch are mingled with the exhaust in the exhaust pipe. The exhaust steam is thus super-heated and expanded, and a powerful, prolonged, pulsating blast is created, which keeps the fuel in a constant state of agitation, and produces more perfect combustion. Some of the beneficial results claimed are: Reduction of back pressure to a minimum (area of nozzle being greater than the steam ports); prevention of ejection of sparks from smoke stack; almost complete absence of noise from exhaust; prevention of formation of cinders in firebox, and a large saving of fuel. A reduction of back pressure in the cylinders without impairing the draft of the fire has long been an unsurmountable obstacle to designers of locomotives, but it is claimed that an engine equipped

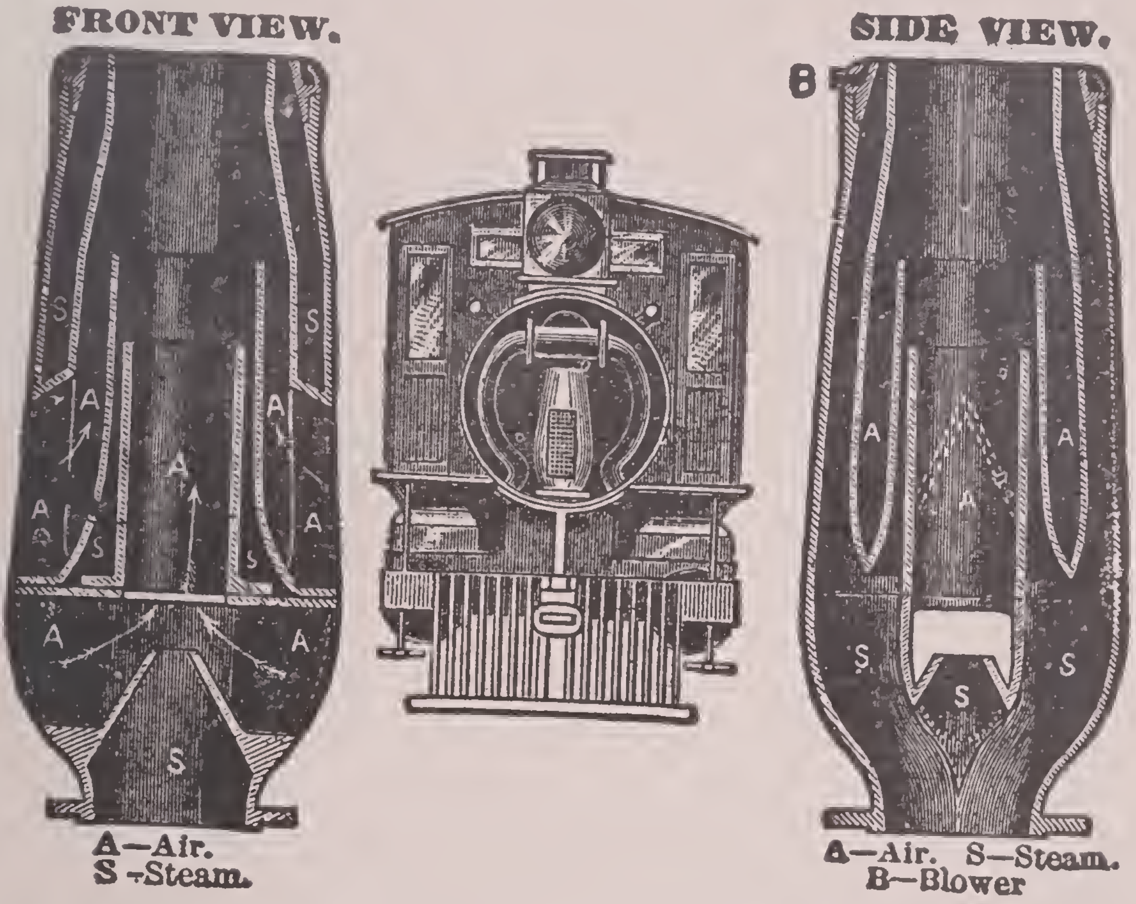


Fig. 17. The Smith Triple Expansion Exhaust Pipe.

with this pipe will pull from thirty to sixty tons more than with the ordinary exhaust pipe. The pipe can be used with either straight or diamond stacks, in long or short fronts ends, and on locomotives burning hard or soft coal, wood or coke.

Draft in Ash Pans. Area of Openings. This is rather a vexed question, and one about which much uncertainty still exists but the consensus of opinion among locomotive builders, and master mechanics appears to favor as large an area for the admission of air through the ashpan as it is possible to secure.

Following are some expressions upon the subject, by prominent master mechanics, and others engaged in the manufacture, and operation of locomotives. One says:

"It is my experience that most ash pans have not opening enough to admit of proper combustion of coal, particularly on engines with deep fireboxes where ashpans are only 10 inches or 12 inches from the rail. To help this matter, we perforate the sides of ashpan and find a decided improvement in the steaming qualities of the engines, and we have no leaky flues from that cause except when ashpans become filled up, thereby shutting off the proper supply of air. If this is not remedied, leaky flues and stay-bolts are the result."

"We have not considered the shape and size of the openings with reference to the kind of fuel and the amount of air space through the grates and I doubt whether it is necessary to consider this further than to make sure that there is ample provision. We have not had much trouble with leaky tubes that we think could be attributed to improper ashpan openings. We have not made an investigation concerning ashpan drafts and therefore can not send you the results."

"We have found that the ashpans of the average locomotive built have been given very little attention; little care has been taken to see that there was sufficient draft under the fire. Most ashpans built have the dampers in the bottom and after the ashes accumulate a little no air can get into the fire, as the ashes stop up the openings. We are following the general rule here of making the ashpans as large and deep as we can. If ashpan is of such shape that these dampers will not give area equal to air space of grates plus 10 per cent., it is good to put aside dampers in ashpans as well, so located that heat can not radiate to the driving boxes. Our troubles with bad steaming engines and leaky flues have been due more to insufficient air openings, causing unnecessary forcing of fires than to too large openings in ashpans."

"I must say that this is one of the subjects that we have not given the necessary time and attention to, to determine proper proportions."

"As a general proposition, we find it necessary to make in our recent locomotives of large size the openings into the ashpan not what we would like to have them but what, owing to the construction of the engine, we must have them. It is common experience that an engine will steam better with a generous air opening in the front of the ashpan so that when moving forward air is forced into this opening and acts somewhat in the nature of a blower. In line with this idea, it is noticed when the openings between the slats of a pilot are filled up with pieces of wood in the winter time, the engine is not as free a steamer as when openings are left between slats. We have made no investigation on the subject of ashpan drafts except that when it is noticed that new types of engines are not steaming, we endeavor to increase the ashpan openings as much as possible. We have not attributed leaky flues in any way to ashpan openings."

"As far as I am aware, this is a matter which has not received very careful consideration on this road, and our practice in regard to openings is not very definite."

"Our rule for designing ashpans varies, of course, with the different styles of engines and pans. For ordinary pans the size of the dampers is governed by the desire to provide ample cleaning facilities. Air inlets at the front end should be provided in firebox at top to guard against leaky tubes. We favor side dampers when it is possible to provide them."

"On another road, it is the common practice to provide from one-seventh to one-eighth the grate area for the damper opening, where a light, quick burning coal is used, while with a heavy, slow burning coal, more ventilation is used. On this same road they say: "We avoid making openings in the front of the pan near the top, as it acts as a check draft on the flues."

There is burned from 125 to 150 pounds of coal per square foot grate surface per hour, and we need 14 pounds of free air per pound of coal burned. On this basis the ashpan should be designed. These openings are usually placed fore and aft in the pan, and if more openings are needed they are made in the side of the pan as near the top as possible. If ashes are allowed to accumulate in the front of the firebox, the air passing through is not sufficiently heated and will cause more or less heat in the tubes."

One reply gave the results of some tests which were as follows:

Compound engine 23 inches and 35x32 inches, grate area 50 square feet, damper openings front and back, 5 square feet. The vacuum in the ashpan corresponded to 6-inch water, which, from a table printed by one of the blower companies, would necessitate the air to move through the opening at a velocity of 3,000 feet per minute, or 15,000 cubic feet of air was delivered through the fire per minute. Since the grate area was 50 square feet there was supplied to the fire 300 cubic feet air per minute per square foot of grate area or 18,000 cubic feet per hour. Assume the temperature of the outside air to be 100 degrees (it will require more cubic feet of air at 100 degrees than if it was cooler), then since one cubic foot air at this temperature weighs .07 pounds, we would have 1,260 pounds air delivered per square foot of grate per hour. One locomotive builder allows 14 pounds air for one pound coal consumption which allows 1,260÷14= 90 pounds of coal to be consumed per square foot grate per hour. On a test of a long firebox engine on the same railroad, figuring the same way as above, 81.6 pounds of coal can be consumed per square foot grate surface per hour, since the grate area was 34.6 square feet, the damper opening 2½ square feet and there was a vacuum in the ashpan corresponding to 1.1 inches water.

We made a series of tests on a cross compound engine having a wide firebox and cylinders 22 inches and 35x28 inches. The opening for the draft to the fire was beneath the mud ring and extended the full length of the firebox on both sides of the engine, and dampers were hinged to the ashpan which could be raised and the draft entirely shut off. These dampers, one on each side were operated from the cab by a lever and so arranged that the opening could be 1 inch, 2 inches, 3 inches, 4 or 5 inches, which opening extended the full length of the firebox which is 74x96 inches long. A quarter-inch pipe extended from the smoke box to the cab and a similar one from just beneath the grates and U tubes connected to them in the cab, the one registering the vacuum in the ashpan being placed at an angle of 30 degrees with the horizontal which gave us a longer range of readings and half of each of these were taken as the correct readings.

On the first test made, the ashpan draft corresponded to one-tenth inch water, the damper opening was 5.48 square feet, which allowed 707 pounds of air per square foot grate surface per hour, and since on this test 11 tons were burned in 12¾ hours, or 35 pounds per square foot grate surface per hour, it allowed 20.2 pounds of air per pound of coal when it actually needed 18 for complete combustion. This test was made with the damper open as wide as possible, giving an area of 5.48 square feet exposed to the atmosphere and two square feet more than when the engine came from the factory.

On the next test the area of the damper opening was 3.48 square feet, the draft .24 inch in the ashpan and 30 pounds of coal was burned per square foot grate surface per hour, thus allowing 28.2 pounds air per pound of coal. The size of the damper openings during this test was the same as when the engine came from the factory, and is ample for the engine when on local freight runs.

The fifth test was run with damper opening area 1.32 square feet when we had 1.3 inches vacuum in the ashpan. Only 29 pounds of coal were burned per square foot grate surface per hour, which allowed 22.7 pounds air per pound of coal, being sufficient for the engine when run in this kind of service. The other tests were made with a view to finding out the results of closing the dampers at stations when switching, and anything else which we might discover. It was found that if the dampers were closed on going into a station and not opened until just before ready to start, the engine would not pop at all, it being impossible to make it do so.

Thus, it is apparent that if the engine does not pop, the fuel is not being burned fast enough to make more than enough steam to supply the engine while switching, and thus a direct saving of fuel is made, but, if the dampers were applied to these engines to be closed when engine was switching or standing idle, it is safe to say that they would seldom be used at the proper time.

These dampers should also prove beneficial in roundhouses, they being kept closed to prevent the circulation of cold air through the tubes, which is detrimental to any engine while warm.

A test was made on a 20x26-inch prairie type passenger engine having a damper opening of 2.5 square feet and a grate area of 41.1 square feet, during which test there was a vacuum of .88 inches in the ashpan, while the coal was being burned at the rate of 56 pounds per square foot of grate surface per hour. With the above vacuum each pound of coal had 11.6 pounds of air for combustion which is not enough.

The firebox on this engine is 78 inches long, and the opening is beneath the mud ring, but it only extends from the front of the grates to a point two-thirds of the distance to the back mud ring, the rest of the distance being closed, due to the trailing wheel's position under the firebox.

On this test there was evaporated 78,533 pounds of water in five and a half hours, of which 14,000 pounds per hour were used in the cylinders, and, since the average speed was 32.36 miles per hour, with 68-inch drivers, this would allow an average cut-off of 19 per cent. As this was a lighter train than the engine will comfortably handle, it is safe to assume that sometimes the cut-off will be increased to one-half or three-fourths for quite a period of time, and it is quite correct to base the maximum steam consumption on three-fourths cut-off at 10 miles per hour, then, by figuring the weight of steam used per hour and assume that seven pounds of water are evaporated per pound of coal, we will have the number of pounds of coal burned per hour, which, multiplied by 18 and divided by 60, gives us the number of pounds of air required per minute for complete combustion.

One locomotive builder gave the average on five different orders of locomotives built for as many different roads as follows:

Ratio ashpan opening to flues .946, and ratio ashpan to cylinder volume 131. The ratio of the ashpan openings to the cylinder volume is probably a better basis to work from than the ratio to the flue area since the draft resulting from the action of the exhaust jet is nearly proportional to the weight of steam exhausted per unit of time.

Prof. Goss has contributed some valuable thoughts upon this subject of air spaces under locomotive grates. Among other things, he says: "I think that one view of the ashpan problem might well embrace the whole apparatus which controls the movement of air from the outside atmosphere through the mechanism of the engine and back into the atmospheric air. If you consider that course you will find that there is first the front end, taking it in reverse order, then the flues, then the grate, and then the ashpan. Now, this movement is stimulated by the action of the exhaust jet, and evidently if any of the elements that I have named is unduly constrained, then the exhaust jet will be called upon to do more work than it otherwise would be called upon to do, to overcome the constrained condition. So, if the opening in the ashpan is small, evidently we must compensate for that small size opening by doing a larger amount of work with the exhaust jet, and if we are endeavoring to get the highest efficiency in all parts of the engine, of course we must not have constrained areas where they are avoidable. Evidently the tube area we can not change materially. That is a factor which is fixed by the general design and proportions of the engine, and we must make our draft act through the tubes at whatever cost. But we do have very great freedom in controlling the opening in the ashpan, and there we should not impose a duty upon the exhaust jet which we can avoid. There are really three ways in which we can check the draft action. We can do it by modifying the exhaust jet; we can do it by modifying the thickness of the fire; we can do it by modifying the area of the opening in the ashpan. I think it is quite true that if engines were always to work at their maximum capacity, our best results would come to us when there were no ashpans, if such a thing were practicable."

(Locomotive Firemen's Magazine)

Extension Front Ends. It is not unusual to find cinders piled up next the front flue sheet, blocking the lower flues. This is obviously caused by little or no draft through the bottom flues, and calls for an inspection of them to see whether they are not stopped up. Unless it is known that the cause of the insufficient draft is too large a nozzle it is better to examine for each of the causes mentioned before making the nozzle smaller.

The shape, angle and position of the deflector has a great deal to do with the proper draft. It should be far enough from the flue sheet to give plenty of room for all the products of combustion that can possibly come through the flues, to pass away from the flues and down to the lower edge of the deflector without any crowding. Possibly the large amount of space where the deflector is placed ahead of the steam and exhaust pipes has something to do with engines with deflectors arranged this way being good steamers.

It is not unusual to drill or punch the deflector at the part next the top rows of flues with a large number of small holes about one-fourth inch in diameter. This will allow a portion of the gases to pass through and stop the cinders, turning them down to the bottom of the smoke arch.

The netting, when very fine, or when a large proportion of the meshes are closed up with cinders jammed in them, can cause a great obstruction of the draft. Thus a coarse mesh netting will cause less obstruction to the draft than a finer one, but as long as the laws of safety in regard to fires being set by live, blazing cinders thrown out of the smokestacks require that these cinders be kept in the front end till they are harmless, we will be obliged to use netting that will hold them back. This requires a fine mesh, and of course a much greater amount of vacuum in that part of the smoke arch above the netting than below it, in order to pull the gases through the netting.

What is known as 2½ mesh netting—that is, having 2½ meshes to the inch, and made with wire .125 inch in diameter—will have in one square foot of netting an area of wire of 75.9 square inches. This subtracted from

144 square inches leaves 68.1 square inches as the total area of the openings in netting of this mesh, or 47.3 per cent. of the whole area.

There are several obstructions to the free passage of the air from outside the ashpan to the space around the jet of exhaust steam. First, the ashpan, which may have insufficient damper openings, or it may be so filled with ashes that there is no room for a proper supply of air to get by. Next the grates, then the bed of coal, and in some cases the ashes on the grates. This requires considerable pull on the air. Next, the resistance offered by the flues, which is increased if any of them are choked up. Then comes the change of direction after leaving the flues and passing under the edge of the apron with force enough to sweep out the cinders that drop on the bottom of the smoke arch. A change of direction of the flow of gases absorbs power, just the same as it does with liquids, although this fact is not given the credit it should have. Lastly, the netting, which probably gives as great obstruction to the flow of the gases as any of the causes mentioned.

The usual method of measuring the force of the draft, or the amount of vacuum produced by the exhaust, and its effect at the various points between the ashpan and the stack is to connect one end of a U-shaped tube to the smoke arch, leaving the other end open to the atmosphere. This tube is party filled with water. When the exhaust or blower is not at work the level of the water will be alike in both legs of the U tube, and the variation of the levels is a measure of the pressure or vacuum in the smoke arch. Ordinarily this difference in level is from 2½ to 4 inches of water with an engine properly drafted and this difference in levels is greatest at or in the stack, next greatest in the front end above the netting, then below the netting, and so on till we get back to the ashpan.

The effect of the exhaust steam depends, first, on the volume of steam passing away from the cylinders, and next on its velocity after leaving the nozzle. From this it is seen that a cylinder full of steam at high pressure will produce more draft than the same cylinder full of steam at a low pressure, and that with an early exhaust the pressure is likely to be higher than with a late exhaust, from the same point of cut-off. Giving an engine more lead will make the exhaust earlier in the stroke of the piston, and thus exhaust the steam at a higher pressure. This is a point well worth remembering—that changing the distribution of the steam in the cylinder can change the pull on the fire that is created by the exhaust steam. Varying the amount of clearance at the ends of the cylinder and in the exhaust port has been known to make considerable difference in the amount of steam used each stroke. Many have an idea that this space can be filled with steam under compression up to about the steam chest pressure. This, of course, requires an earlier exhaust closure of the main steam valve.

A locomotive is said to be a good steamer when the boiler can make more steam than the engine needs to draw the full train. It is evident that if the boiler makes only a little more than the engine uses the pressure will be held up. Now if the engine is extravagant in its use of steam it may be beyond the possible capacity of the boiler to supply it. Such a locomotive is usually very wasteful of water, and by the unusual amount taken to do the work the probable defect in a poor steaming locomotive may be located.

There are many theories for the drafting of a locomotive boiler; some of them are shown to be correct when put into practical operation; others are of no avail. For this reason many locomotives have to be drafted on the "change and try" method till the trouble is found by the effects of the remedy applied. One locomotive may be drafted after a certain plan and give the best results, while another one of the same size and type, running on the same trains, will need some other changes to make it a success.

Very often this is because superficial observation seems to show that they are exactly alike, when tests closely made of drafting arrangements and the *steam distribution* would show that they are essentially different in some important particular.

The proper method when making changes in the drafting arrangements in order to make an engine a good steamer is to make only one change at a time and note the effect. If more than one change is made it may be impossible to tell which one of the changes is a move in the right direction and which one is wrong. First see if the ashpan will admit sufficient air; then see if the grates have enough air opening; then note if all the flues are clear; and last if the netting is clean.

STANDARD SMOKE BOX FRONT, PENNSYLVANIA RAILROAD.

In standardizing the locomotive equipment on the Pennsylvania Railroad, the treatment of smoke box fronts and doors is noteworthy as representing a departure from the usual practice. The various sizes and styles of fronts adapted to the different classes of locomotives have been discarded, and a special design of front substituted that can be fitted to any class.

The standard front is shown in the illustration (Fig. 17a) and while it does not present any special feature of design, the method employed in applying it to the smoke

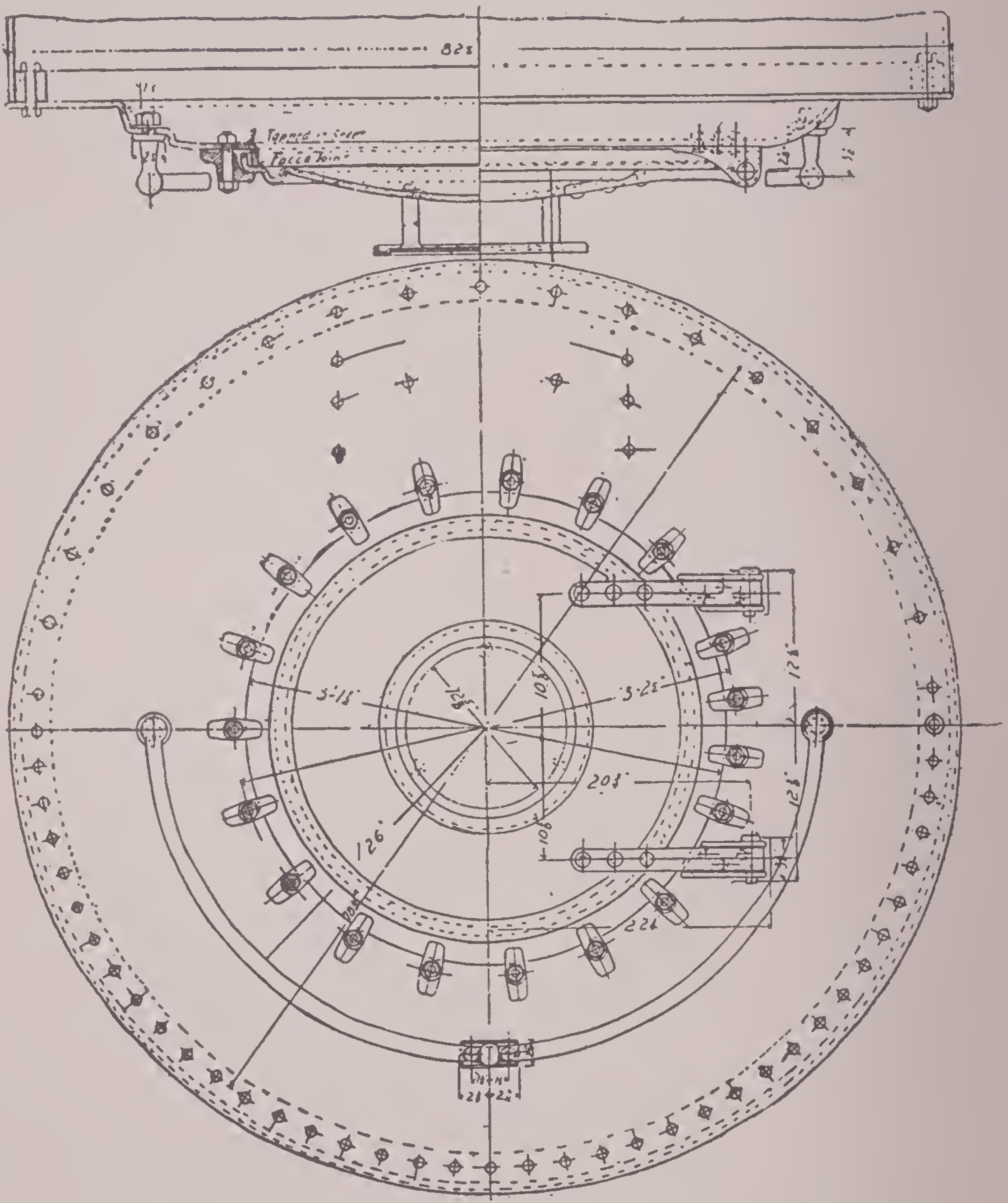


Fig. 17-a. Standard Smoke Box Front and Door.—Pennsylvania Railroad.

boxes of various diameters is original and interesting. The front is made of ½-inch pressed steel and sufficiently large to fit a smoke box 82 inches in diameter, which is the largest on the Pennsylvania system. For smoke boxes of smaller diameters, the front is cut down in a boring mill to suit the sizes of the various classes of locomotives, according to tables provided for this purpose. The outside bolts are laid off from a templet and drilled and the front is then applied in the usual manner.

The front is adaptable to all smoke boxes from 82 inches down to 63 inches in diameter and the sizes given include the principal classes of locomotives on the Pennsylvania system.

It is apparent that this plan presents a number of advantages over the usual method. Only one die is necessary for pressing plates, a provision which simplifies work in the flanging room, and has the further advantage of reducing the number of fronts carried in stock at the various shops and store houses.

An improvement in the general appearance of locomotives in so far as symmetry is concerned, is obtained by fitting them with fronts and doors of the same design. The method offers an advantage in obtaining fronts for disabled locomotives at outlying roundhouses, as the front desired can be sent finished from the main shop on receipt of information stating the class of locomotive the front is wanted for. It is obvious that in building new locomotives the method can be successfully applied with a saving of both time and expense.

Grate Bars. The grate bars being a part of the engine in which the fireman is particularly interested, a brief description of a few of the leading types will be given.

The old-fashioned grate bars for burning wood are too familiar to need describing, being simply plain cast iron stationary bars with narrow slots between them. For soft coal various styles of rocking grates are used. Figs. 18 and 19 show plan and sectional views of rocking grates. The method of shaking is also illustrated in Fig. 19, together with the dump grate at the front to be used when cleaning the fire. For burning hard coal a larger grate area is required than with soft coal, for the reason that a hard coal fire must be kept more shallow than a soft coal fire. The grate for hard coal is long, and instead of being made of cast iron it consists of horizontal wrought iron water tubes in connection with the water space, thus permitting a free circulation of water through them. This plan not only prevents the grates from burn-

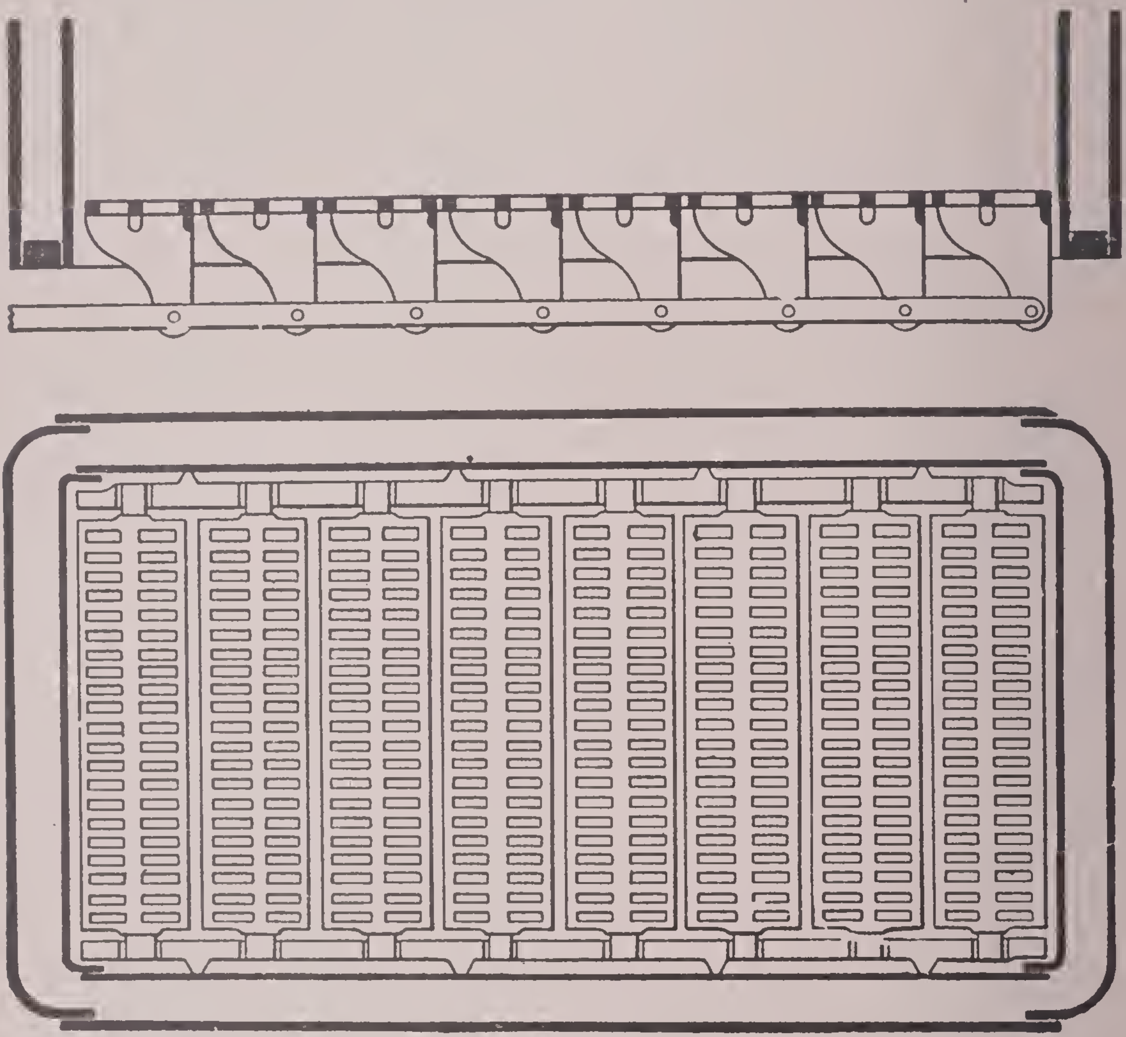


Fig. 18.

ing out, but it also serves to utilize a portion of heat that would otherwise be wasted.

Fig. 20 shows a plan and Fig. 21 an elevation of a set of water grates. Provision is made for drawing or cleaning the fire, by making every fourth or fifth tube solid and allowing it to project clear through both walls of the back end of the fire-box through thimbles inserted for that purpose. These solid tubes have rings on their back ends by which they may be withdrawn, and the front end rests upon a bearing bar.

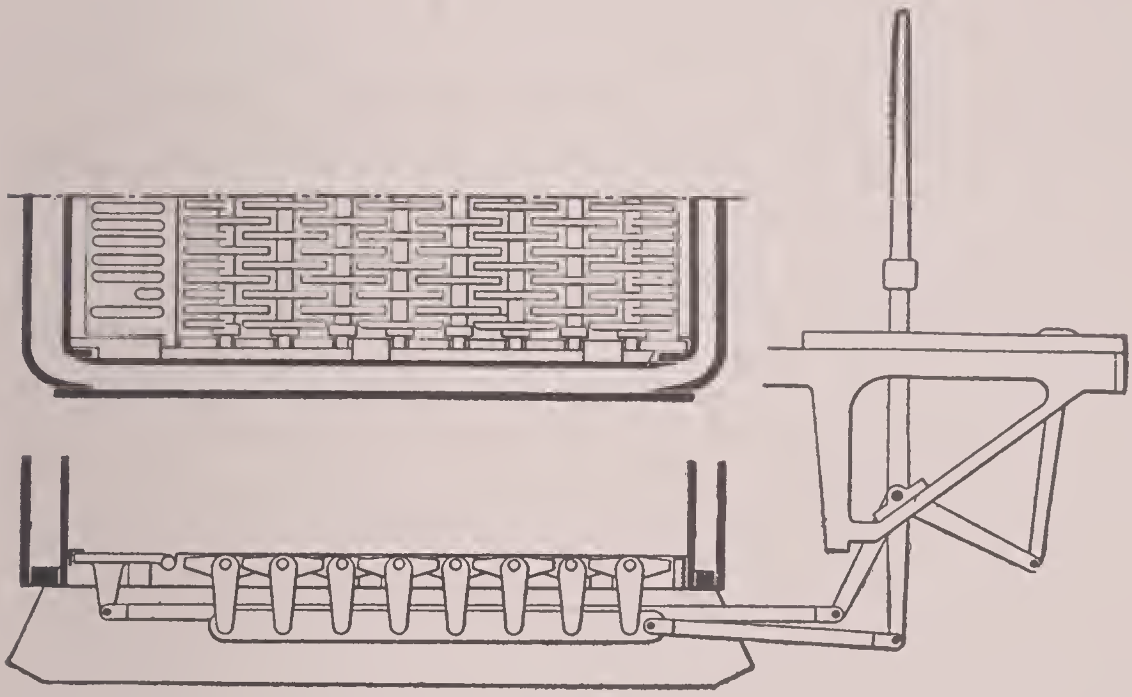


Fig. 19.

The tubes of a water grate are made water-tight by being caulked into the inside sheet at the front and back ends of the fire-box.

About twenty square feet of grate surface is needed to burn one ton of soft coal per hour.

When the fire becomes dull and heavy, caused by ashes accumulating on the grate bars, the grates should be shaken up, which is best done while the engine is working at a moderate speed, or at least when the blower is on.

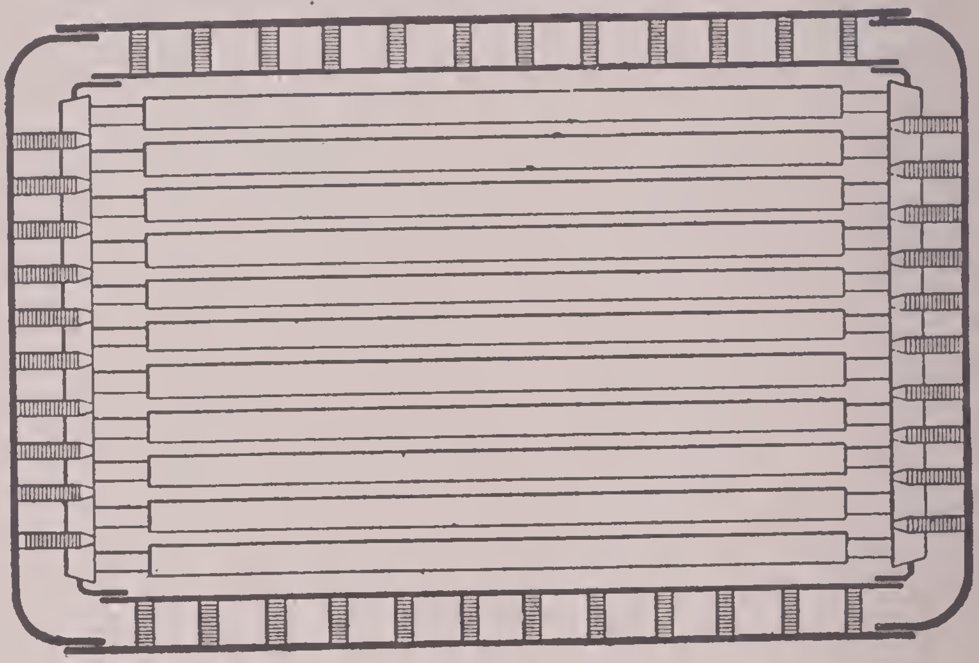


Fig. 20.

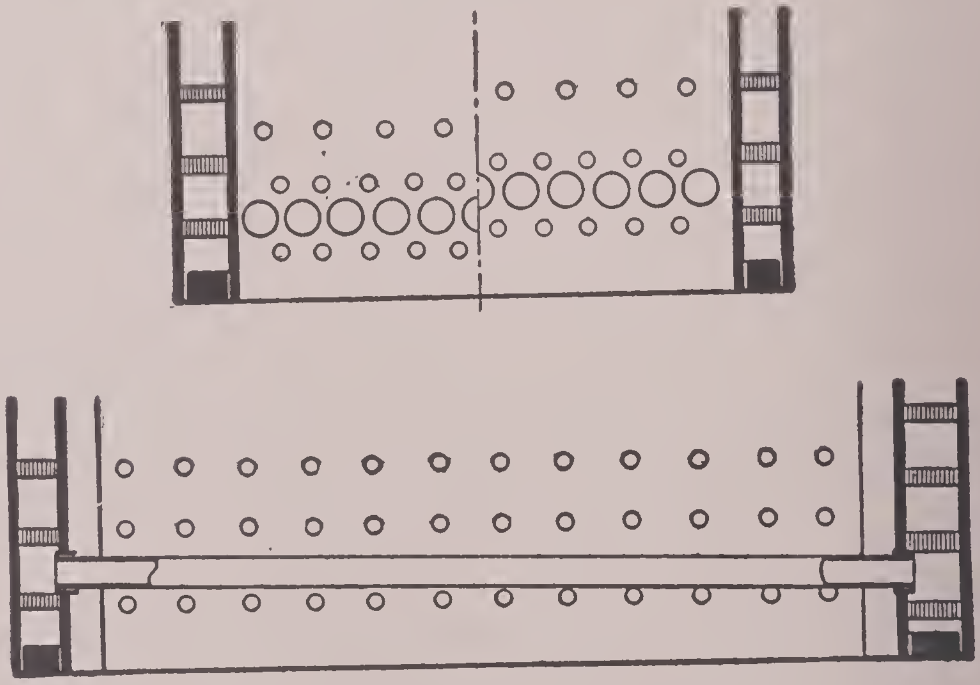


Fig. 21.

The ash pan should be kept clean and free from ashes. This will allow a free draft of air and prevent the burning out of the grate bars.

LABOR SAVING DEVICES FOR THE FIREMAN.

BREWER PNEUMATIC FIRE DOOR OPENER.

The occupation of locomotive firemen is one requiring a great deal of exercise, especially if the engine is on a long freight run, and consuming 15 to 20 tons of coal on a run. Some expert has calculated that for each ton of coal that is shoveled into the fire-box with a No. 4 scoop (holding on an average 17 pounds of coal), the fireman is required to make 585 distinct movements, as for instance, with each scoopful there are five movements divided up as follows:

1. Filling the shovel with coal.
2. Opening the door.
3. Picking up the shovel.
4. Throwing the coal into the fire-box.
5. Closing the door.

Therefore the burning of ten tons of coal requires 5,850 distinct movements on the part of the fireman, and twenty tons would necessitate 11,700 movements in order to place it where it would do the "most good." Any device that will tend to save some of this hard labor should certainly be warmly welcomed by the fireman. The Brewer Pneumatic Door Opener appears to be deservedly working its way to the front as not only a labor saver, but also a fuel saver, and by its action in opening and closing the firedoor almost instantaneously it also protects the flues, as it prevents the large volume of cold air from entering the fire-box with each shovelful of coal,

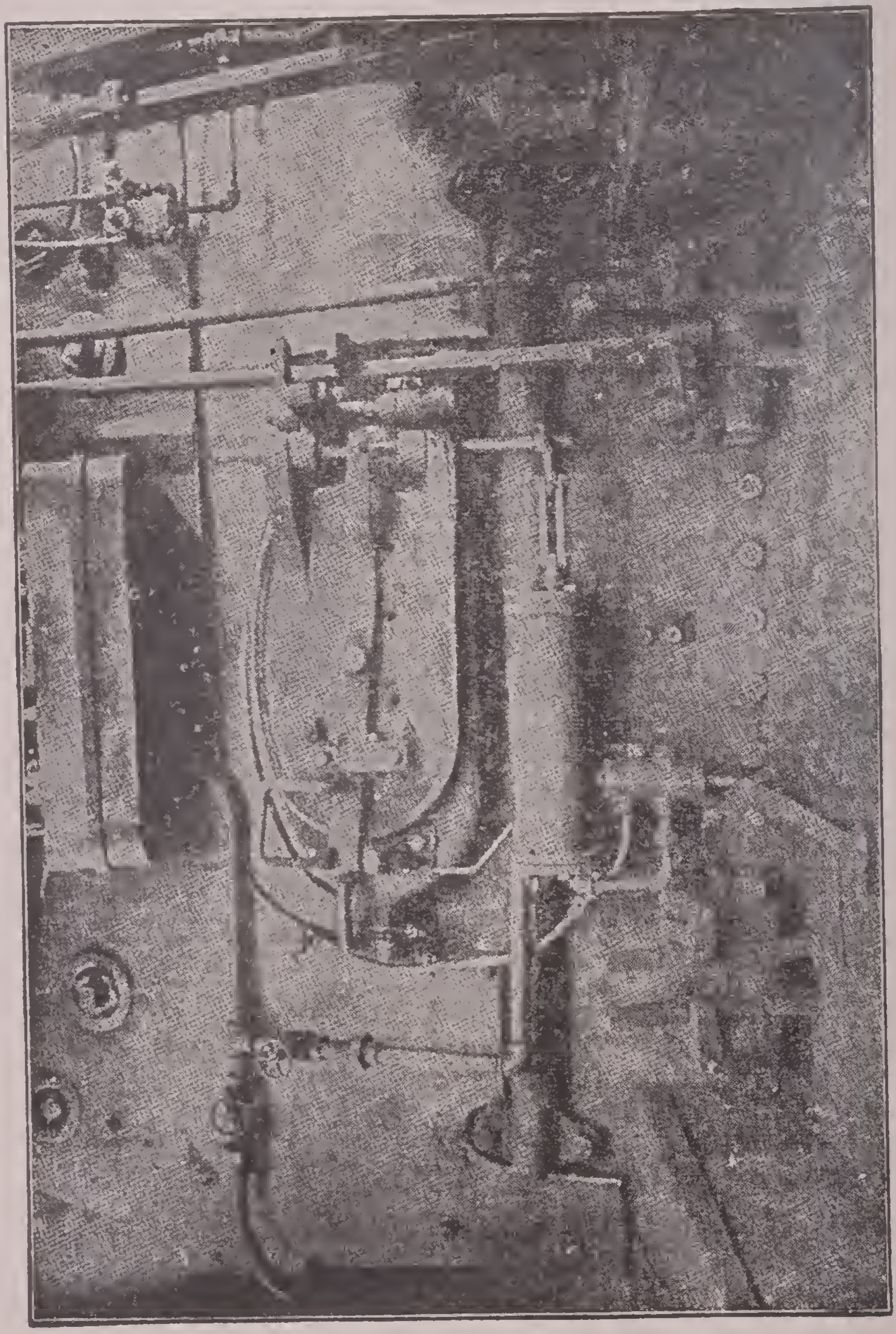


Fig. 22. Brewer Pneumatic Door Opener, Full View.

which is unavoidable with the old style method of opening the door. The sudden cooling of the back ends of the flues is thus, to a large extent, prevented, while at the same time the single shovel system of firing is insured.

The apparatus is simple and durable, having very few parts, and therefore does not easily get out of order. It is clearly shown in the accompanying illustrations, which are self-explanatory. The quantity of air required to operate it is very small, almost imperceptible. It consists of a small horizontal air cylinder directly underneath the door. This cylinder is fitted with a piston, the rod of which is connected by means of a link and short arm or crank to the pivot upon which the door swings. The motion of the door in opening or closing is very rapid, but the door does not slam, as there is always a cushion of air to prevent this. The door is opened by simply placing the foot upon the treadle or trip shown on the deck. This action opens the air valve, admitting air to the cylinder, thus forcing the piston to move towards the right. To close the door, remove the foot from the trip, allowing the air behind the piston to escape. This permits the door to swing shut. This device is being used quite extensively on the Chicago, Rock Island & Pacific and other roads.

Fig. 22 shows a full view of this device, and Fig. 23 shows sectional front and side views.

THE BATES FIRE-BOX DOOR.

To make clear the action of this door, it should first be said that a shield or deflector is projected downwardly and into the fire-box from the upper portion of the door,

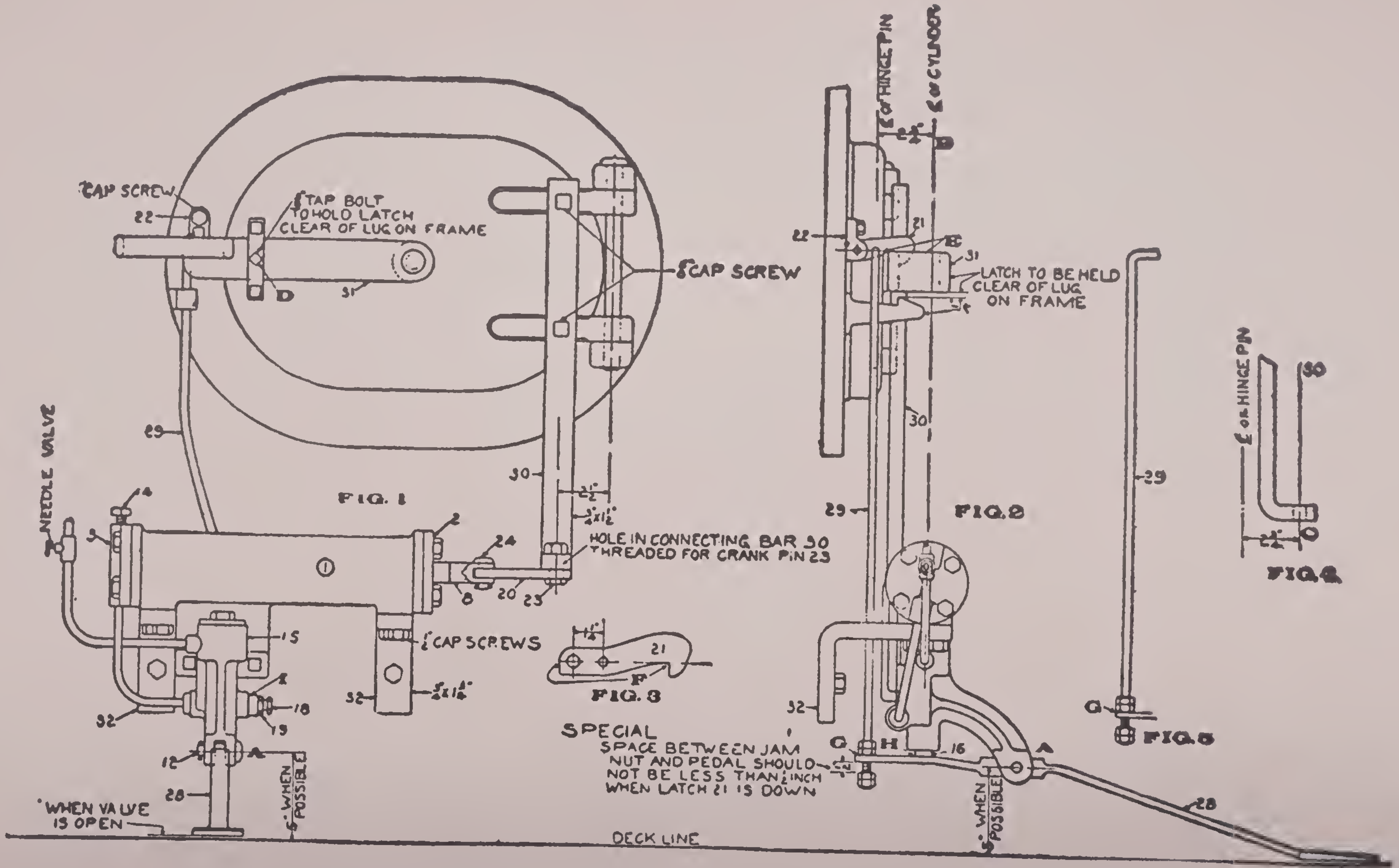

CAP SCREW
22
TAP BOLT TO HOLD LATCH CLEAR OF LUG ON FRAME
D
31
CAP SCREW
NEEDLE VALVE
29
30
FIG. 1
4
3
2
24
①
8
20
23
HOLE IN CONNECTING BAR 30 THREADED FOR CRANK PIN 23
15
CAP SCREWS
32
18
19
12
A
28
WHEN VALVE IS OPEN
WHEN POSSIBLE
21
F
FIG. 3
SPECIAL
SPACE BETWEEN JAM NUT AND PEDAL SHOULD NOT BE LESS THAN ½ INCH WHEN LATCH 21 IS DOWN
DECK LINE
℄ OF HINGE PIN
℄ OF CYLINDER
B
E
LATCH TO BE HELD CLEAR OF LUG ON FRAME
FIG. 2
G
H
16
FIG. 5
℄ OF HINGE PIN
30
FIG. 4

Fig. 23. Brewer Pneumatic Door Opener, Sectional, Front and Side Views.

and that there is also a similar, but shorter, deflector from about the mid-height of the door to prevent coal from lodging in the furnace doorway. It is clear that the purpose of these deflectors is to insure the delivery of the coal and also to direct the air currents in their passage into the fire-box. Fig. 24 shows the door with the upper half A opened and in the usual running position. The air deflector B is also well illustrated. The firing is done through the opening shown and a small scoop is used. This open position of the upper half of

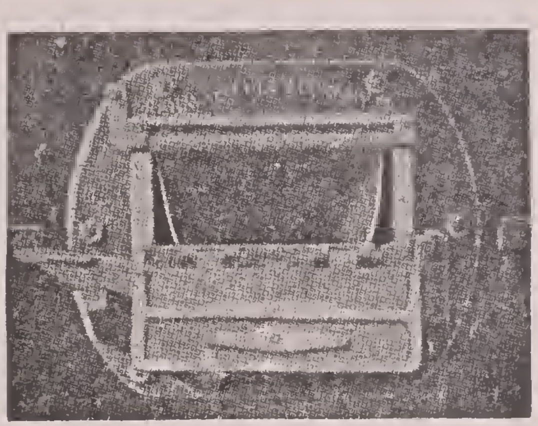


Fig. 24.

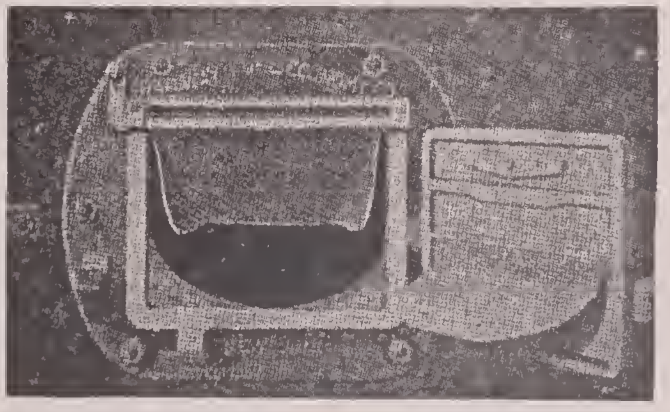


Fig. 25.

the door is maintained at all times, except when the fire is cleaned at the end of the run. Fig. 25 shows the entire door swung open as for the last-named service, and also shows the lower deflector at the middle of the door, earlier referred to.

In firing with this door coal must be used in small quantities, at comparatively short intervals, and it is necessary to use a brick arch. With these arrangements the introduction of oxygen, mingling with the gases, produces an increased efficiency, due to the consumption of what is commonly the waste products—the gases—and strong testimonials from well-known superintendents of motive power and also from engine crews who have used the door have been received. The saving in fuel and the betterment of steaming qualities of the boiler, as well as the almost total absence of black smoke, are well attested. The device has been used on Southern Pacific locomotives for several years, and more than 500 locomotives on the road now have it. It is also being used on many other roads.

A striking instance of economy brought about by the use of this door has been called to our attention. On one road having a number of consolidation engines that did not steam up to their duty, an estimate for remodeling the fire-boxes of all of them indicated that an outlay of several thousand dollars would be necessary. The Bates fire door was tried before the work of remodeling was undertaken, and it worked so well that there was no longer any difficulty in making steam, and the fire-boxes were therefore not remodeled. A point in favor of this device is its cheapness and simplicity. It can readily be fitted to any size or shape of fire door opening, and where a fire-brick arch is already in use no alteration of the fire-box is necessary, but it is necessary that the brick arch be kept in close contact with the sides of the fire-box, in order to obtain the best results. The reason for this is clear.

THE MECHANICAL STOKER.

The following plain, sensible remarks upon the subject of mechanical stokers for locomotives are copied from an article published in the Railroad Gazette in 1905. We quote:

"Railroad men and those interested in railroad work have for some time been asking themselves and each other as to the probable upper limit of size in locomotive construction. Matters have gone forward with such leaps and bounds during the past twenty-five years that one has been obliged to be on the alert in order to keep in touch with the advancement that has been made. Locomotives with from three to three and a half times the heating surface of the ordinary practice of the early eighties are now so common as to attract hardly a passing notice, and no one feels sure that the end has come.

In all of this growth, we have heard much of the strength of material, the efficiency of heating surface, the proper loading of bridges and track and the economy of high steam pressures and heavy loads, but hardly a word about the man.

Unfortunately, he remains the same as in the days of small engines, while the only consideration that he has received is in the limitation of the length of the fire-box. Practical working with extra long fire-boxes showed them to be impossible when considered from the physical standpoint of the man; firemen were found to be incapable of throwing coal to the front of such a box with any certainty of placing it where it was needed. So there has been a limit placed upon the length of this part, though in other respects the modern locomotive seems to have been developed regardless of the man who is to feed its furnace.

The fatigue of those who fire large engines over a long division and the complaints arising from this over-exertion have been so pronounced that the subject of placing three men on these engines has not only been seriously considered by railroad men, but has been aggressively demanded by the labor organizations. The matter has already been brought to the attention of the legislatures of Indiana and Ohio, with the view of making it a legal requirement that two firemen be used on such machines. The railroads object to this for the reasons that the second man will increase the expense and probably decrease the efficiency of the whole crew. The argument of the men is, however, a potent one, that the work demanded is more than the average fireman can perform.

That there is much of truth in this there can be no doubt. Just what the railroad companies lose by this over-exertion of the men no one knows, though it would be interesting to determine the difference in the total efficiency of the locomotive between the first ten and the last ten miles of a hundred and fifty-mile run, attributable to the loss of efficiency or fatigue of the man. At any rate, the railroads are being pressed to put a larger crew on the big engines. Their saving defense will be that more than two men are not needed, and to prove this latter point the assistance of some form of mechanical stoker will have to be invoked. For many years the air has been full of talk and speculation about the availability of such a device, and one or two forms have been tried, with more or less success, in an experimental way, but no road as yet has either adopted one or made an application on a large scale.

The prospects are, however, that the preliminary work along these lines is emerging from the tentative and experimental and entering upon the practical stage of development, when the mechanical stoker may be expected to work with all the reliability of the injector, or the air brake, or any of the other attachments that in their day have passed through the disheartening period of experimental work. In what the stoker is now doing, it has been demonstrated that it is capable of distributing the coal evenly over the surface of a large fire-box; of maintaining steam pressure under a wide range of requirements, and of picking up a pressure that has been lost through inattention on the part of the fireman. That it is successful on these points there is ample proof. It might win out on all of these counts, however, and still fall far short of being a commercial or mechanical success, if it added to the labors of the fireman, or wasted coal.

THE VICTOR LOCOMOTIVE STOKER.

The Victor Locomotive Stoker is the successor to the Kincaid Locomotive Stoker, which was invented by Mr. John Kincaid, who was for many years an engineer on the Chesapeake & Ohio R. R.

Necessity is, and always will be, the "mother of invention." Conditions arise which can only be met with approved ideas and approved methods, and the increased traffic, both in the freight and passenger service of all the prominent railways, has necessitated heavy power engines of approved types and enormous size, in order to accomplish desired results. In fact, the engines have grown beyond the capabilities of the firemen, and as the latter could not be reconstructed or endowed with greater strength and endurance, mechanical means became the only logical solution of the problem.

To meet these conditions, and to relieve the fireman of the severe and exhaustive drudgery imposed upon him, the inventor, himself a Brotherhood engineer, and a former wielder of the scoop, designed his now famous stoker. It was not designed to degrade the fireman's position, but to exalt it; not to make his duties within the province of "cheap men," but to put a premium upon his intelligence; to give him greater opportunities to study and thus hasten the time of his promotion to the position of engineer.

The merits of Mr. Kincaid's invention are manifold, but prominent among them are—

Its ability to fire an engine without opening the door, thus relieving the fireman from the extreme heat of the fire-box; to scatter the coal in small quantities over the whole grate area, just as the needs of the engine require, thus obtaining almost perfect combustion, the reduction of the smoke and spark nuisance to a minimum and to insure the greatest possible saving in coal. A higher and more uniform steam pressure can thus be obtained; less clinkers are formed; longer runs can be made without cleaning the fires; as the stoker fires without opening the door, the in-rushes of cold air from frequent opening of the fire-door are eliminated, and the fire-box sheets and flues are protected from sudden contractions

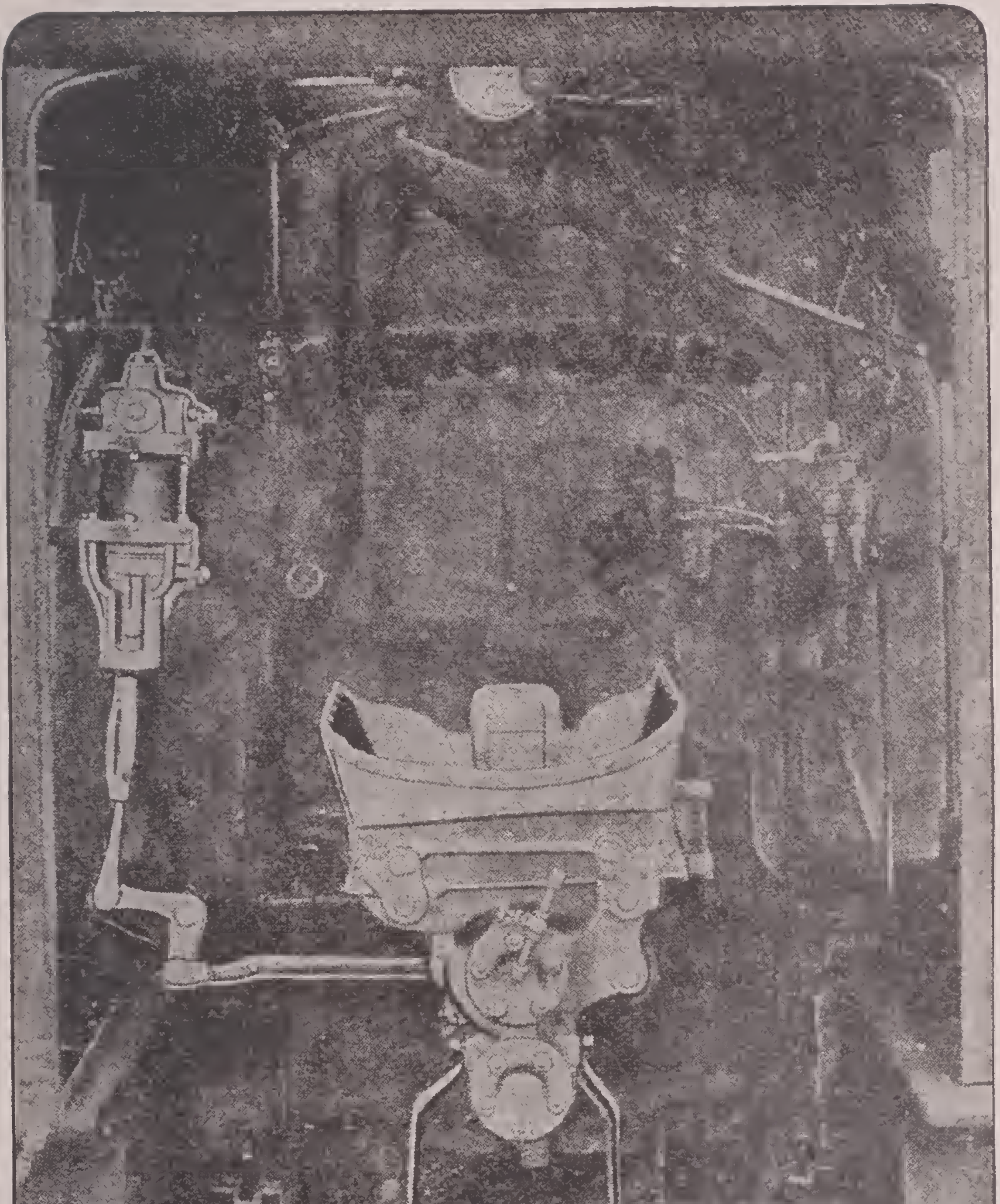


Fig. 26. Victor Mechanical Stoker.

and expansions; thus the chief source of leaks in the furnace are practically overcome.

In firing with the stoker a much lower grade of coal can be used than is possible in hand firing and still accomplish as good or better results. Nut and slack coal is always preferable when using the stoker.

These stokers have been in operation since January 1, 1905, attached to locomotives with wide fire-boxes, and to locomotives with long fire-boxes, used on all classes of passenger service. The result of this work has proven beyond all question that the stoker will do its work efficiently and economically and that the fireman, having once become acquainted with the stoker and recognizing its labor-saving features, becomes its enthusiastic supporter.

The continuous feeding of coal has a very marked effect upon the amount consumed. Run-of-mine coal is used, but it has been found that a good grade of slack will secure even better results owing to the principle of feeding coal in small quantities widely distributed. Absence of dense volumes of black smoke is also very noticeable.

Figure 26 shows the stoker as it appears in the cab, the small controlling engine required to operate it being located on the boiler-head on the fireman's side.

The following are the dimensions of the apparatus: Length over all, 47 inches; as three inches of the trough enters the fire-door, the stoker extends back on the deck 44 inches; width over all, 24 inches; height on short legs, 28 inches.

Figure 27 shows the stoker as attached to the furnace of a locomotive. A represents the hopper which receives the coal; B the plunger-trough through which coal is propelled into the furnace; C the stoking cylinder; D the rotary valve; E the furnace door; F the controlling engine, and at the left of the furnace door, the steam pipe extending to the locomotive boiler; also the valves and choke-plugs of the stoker, arranged for the convenience of the fireman in regulating the operation of the machine.

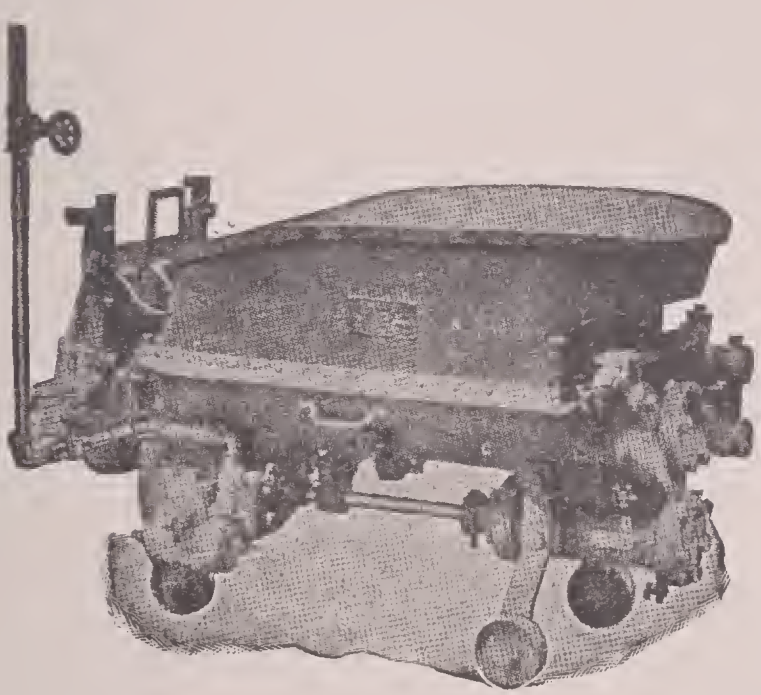


Fig. 27.

The illustration in Fig. 27 shows the controlling engine connected underneath the stoker. Fig. 28 is a transverse view from Fig. 27, and shows the head of the plunger and its position in the trough at the end of each stroke; the conical deflector, attached to the inside of the door, which spreads the coal in the fire-box, and when the stoker is removed, may be turned up to close the hole occupied by trough. The rocking-shaft connected with the controlling engine, which transmits power to the rotary valve, D, and to the conveyors in the hopper; also the end of the trough, in which the plunger travels, and the exhaust steam port are likewise shown in this illustration.

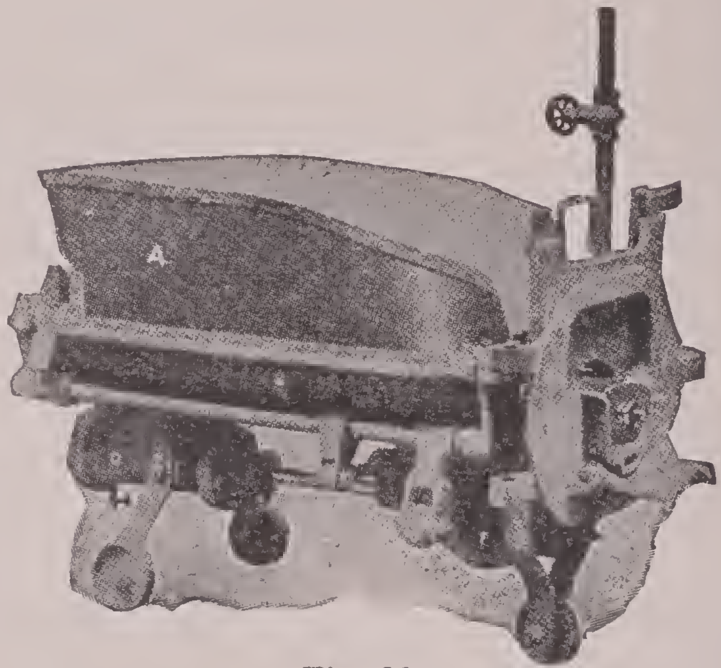


Fig. 28.

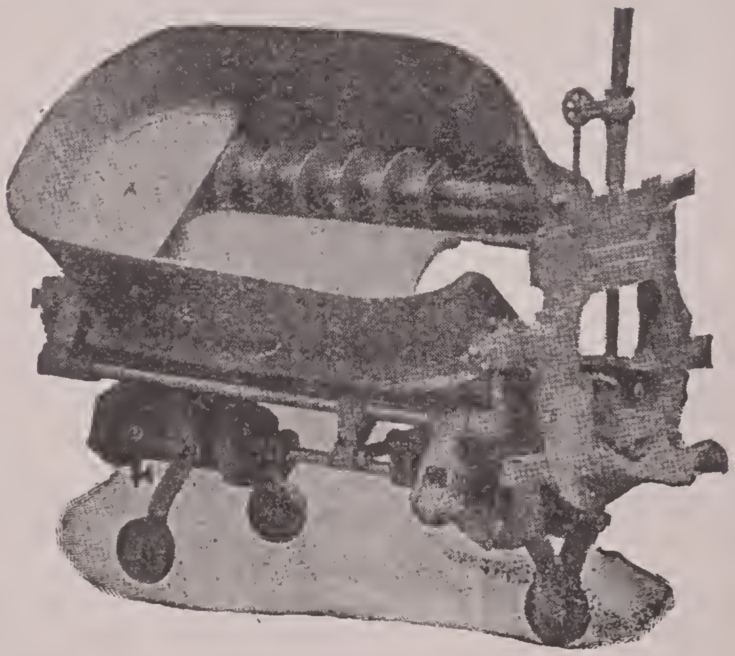


Fig. 29.

Fig. 29 shows the hopper raised, and reveals one of the twin spiral conveyors which carry the coal forward; it also shows the opening through which the coal drops onto the apron after leaving the conveyors, and, when apron is retracted into the trough, to be thrown into the fire-box by the next forward stroke of the plunger.

Description. The stoker consists of the following essential parts, viz.: First, a main cylinder and a trough in which reciprocates a piston and plunger which with a variable stroke throws the coal to the different portions of the fire-box. This variable stroke is given to the plunger by means of a rotary valve, three separate steam ports leading from said valve to the rear end of the cylinder, and three choke plugs, one for each of the said steam ports.

Second, a small controlling engine. It has been found by experience that the most desirable location for this engine is on the boiler-head on the fireman's side. This removes the liability of condensation and consequent dryness of engine parts when placed on and beneath the stoker itself. The steam for the operation of this engine is taken directly from the dome.

Third, a hopper with two spiral conveyors journaled in the bottom of the hopper pan. The conveyors carry the coal to the front of the hopper, onto the apron of the plunger, giving a regular and uniform feed. The speed of the conveyors may be increased or diminished by giving more or less steam to the controlling engine, as may be required. This also increases the number of strokes made by the plunger, but does not affect the plunger's velocity, or in any manner affect the distribution of the coal in the fire-box, the latter being governed by the three choke plugs.

Fourth, a small steam chest containing a rotary valve which regulates the number of strokes made by the plunger.

That portion of the stoker forming this valve chest is cast in one piece with the main cylinder and has three separate steam ports leading to the rear end of the cylinder for the admission of steam behind the plunger or piston. These steam ports terminate in one common port before entering the rear end of the cylinder, first through a small preliminary port at the end of the cylinder (which also acts in the form of compression by retarding exhaust on the last portion of the return stroke), and after the piston has advanced a short distance it uncovers the main port, which also leads from the common port, giving free passage to the steam.

A choke plug is placed in each of the three steam ports between the valve-sleeve and the common port. The office of the three choke plugs is to vary the amount of steam reaching the rear end of the cylinder through the various ports and thereby giving a variable stroke to the plunger.

The valve operates in a rotary manner, each of the ports stopping fully open in front of its corresponding steam passage in regular succession: Beginning with No. 3 (the port nearest the rear of the stoker), the steam, after leaving this valve, passes through port No. 3 into the common port and the rear end of the cylinder. Choking down this steam port until it is almost closed causes a very light stroke of the plunger, distributing the coal over the grate near the fire-door. The other two valves operate in the same manner, each taking its respective turn. They are adjusted so that more steam is admitted on the second stroke than on the third, thus distributing coal over the middle portion of the grate, and more on the first than on the second, thereby scattering coal over the front end of the grate. By this adjustment of the choke plugs any range of distribution can be obtained that may be desired.

The rotary valve and cylinder are provided with suitable live steam and exhaust ports for the return of the plunger and the exhaust steam from each end of the cylinder. In the front end of the main cylinder is a very small live steam port, connected directly with the live steam supply, and its office is to return the plunger after its forward stroke and also to add volume to the steam retained after the piston has passed over the forward exhaust port, thus giving the desired compression to prevent the piston ramming the front cylinder head. By means of a valve this port can be enlarged to give increased compression necessary when expelling water from condensed steam in starting the stoker when it is cold.

Fifth, the furnace door.

Each machine is supplied with a furnace door made to fit the standard door-frame of the locomotive to which the stoker is to be attached. This door has an opening to receive the stoker trough and is provided with suitable brackets for holding the machine in position. Cast upon its inner side are curved lugs, which serve the purpose of hinges for a deflector for spreading each charge of coal over the width of the fire-box. The end of this deflector can be raised, if necessary, to aid in the distribution of coal, by means of a set-screw directly under its center. It also has a small vertical sliding door for inspecting the fire, and the deflector can be turned up vertically and held in place by a latch to close the trough opening when the stoker is removed.

To OPERATE THE STOKER.—*Directions for Firemen.*—Don't fail to be on your engine *at least* 30 minutes before leaving time.

Know for yourself, before starting, that you have the necessary tools with which to do your work. If they are not on the engine, report the matter to the round-house foreman, and don't go out without them.

A fireman's outfit should consist of 2 scoops, 2 hooks (one 12 feet and one 7 feet), 2 torches, one coal pick, and one ash-pan scraper.

Before leaving the round-house, examine the shaker rigging and know before starting that it is O. K. Also see that the ash-pans are clean.

To build the fire break every particle of bank. Be careful not to get green coal on the grates. Spread the fire evenly over the entire grate area, then attach the stoker.

Assist the engineer all you can in getting the engine ready, but *never* neglect *your* work to do his. Always manage to keep the oil cans and torches filled and ready for immediate use.

Be sure the steam is turned on next to boiler. If you have a reducing valve set the gauge at about 60 or 80 pounds; if not, about one-half turn on the globe valve next to the boiler is sufficient. Before admitting steam to stoker *always* open the *admission valve* to front end of cylinder to prevent the piston from ramming the front head. Leave this valve open, until the condensation is thoroughly blown out, and machine heated up to steam temperature. Then close and *leave it closed.*

Regulate the speed of the stoking piston by the throttle valve to the *controlling engine.* Run the machine slowly at first until enough steam is held in the cylinder on which to cushion the motion of the piston.

STARTING THE STOKER.—*Turn on the steam gently, allowing sufficient time for condensation to blow out.* (Turning on a full head of steam before condensation is exhausted will burst this cylinder the same as it would on any other engine.) This may require a little time, as the steam ports are small. If there are any drain cocks on the stoker, see that they are open before turning on the steam. If there are none, considerable water will appear at the mouth of the stoker trough when starting the machine. This comes from the exhaust, and is caused by the steam coming in contact with the cold metal of the machine, but will disappear in a few minutes, or as soon as the circulation of steam has warmed up the cylinders. Should the piston head hit the back cylinder head on the return stroke open choke plug No. 3 to let in enough steam to cushion. If water appears at the exhaust after the machine has been in operation for some time, it indicates too much water in the boiler. As soon as steam has been turned on at the boiler, open the globe valve in the steam pipe leading to the small engine. This is the throttle valve for the small engine, and the amount of steam admitted by it regulates the speed of the conveyors and the number of strokes made by the plunger. To run the machine fast or slow increases or diminishes the amount of coal fed into the furnace, but does not affect the distribution of the coal in the fire-box. Should controlling engine be lazy about starting touch one of the tappet rods at either end of the floating valve.

To Regulate the Choke Plugs.—To regulate the choke plugs for the distribution of coal in the fire-box, wait until the steam has reached the maximum pressure and machine is working; then with all the choke plugs wide open, turn on enough steam at the throttle valve to throw the coal near to, but not strike the flue sheet; then close down the middle choke plug (No. 2) until this charge falls near the center of the fire-box; then close down the choke plug No. 3, next to the back end of the stoker, until the coal drops inside the furnace door. This gives a distribution over the entire length of the fire-box. Don't fill the hopper with coal when regulating the choke plugs or you will get too much coal in the fire-box, and waste fuel. Use only one or two scoopsful at a time and watch the distribution in the fire-box.

In regulating the choke plugs when the engines are standing, be careful not to make the strokes too heavy, as the draft will assist in carrying the coal forward when the engine is working. Never try to regulate choke plugs with the front end admission valve open. If the steam drops 20 or 50 pounds while the stoker is in operation, open the throttle valve accordingly, unless some form of steam regulator is used. If, after running some time you find the stoker piston only making half strokes, examine front end admission valve and you will find it was not entirely closed or accidentally opened. Close this as far as you can and remedy the trouble.

Operating the Stoker.—In operating the stoker on large engines with a heavy train, usually 20 to 30 strokes of the plunger per minute is sufficient, providing the hopper is kept full. The speed of the stoker can be varied from 12 to 40 or more strokes per minute. The speed of the stoker should be regulated to correspond with the work the engine is doing. Before starting out on a run, see that the entire surface of the grates is covered with fire. A heavy fire is not necessary, as better results can be obtained with a thin, bright fire. Avoid heavy firing. Remember the stoker is at work continually and there is little danger of the fire getting away, but don't neglect it when the engineer shuts off steam. Remember your fire is lighter than when firing by hand, and will die out quicker. *Notice the condition of the fire often.* This can be done by means of the small vertical sliding door above the stoker trough. If you can't see take your long hook and feel your fire occasionally. If the fire should become banked near the door, open up the choke plug No. 3 until this charge of coal goes beyond the bank; if the fire becomes banked near the flue sheet, close down the choke plug No. 1 slightly. If the fire is too light near the door or flue sheet, the reverse action should be taken; if the fire is too heavy in the center of the fire-box, notice the choke plug No. 2, and if this is firing in the right place either open up the choke plug No. 1 or close down choke plug No. 3 slightly, or both, as this may happen by having the third stroke too heavy and the first too light. As a general rule, when the choke plugs have once been regulated, it is seldom necessary to change them. However, it is better to change the plugs than to hook the fire. If a bank is found anywhere in the fire, it can generally be burnt out without using the hook, by changing the choke plugs. With engines having a severe draft, considerable coal may be carried in by the draft before the plunger strikes it. This with some engines, is distributed over the back part of the grate, and with some engines it is distributed near the center. In either case the choke plugs should be regulated to suit these conditions. The coal should be broken as fine as possible, as much better results can be obtained. Railroads having the stoker in use should furnish nut and slack. It is much cheaper and the stoker will do better work with it.

In taking stoker apart be very careful not to lose nuts, bolts or other small parts, the loss of which might disable the machine.

Always keep the packing around the main piston rod tight. If this gets loose the steam used for cushioning the forward stroke escapes, causing the piston to strike front head.

DRIFTING DOWN GRADES.—While drifting down a long grade it is only necessary to feed enough coal into the firebox to keep up the heat and not let fire get too low. It has been suggested to build up a pretty good fire in the firebox before starting down grade and then to use the blower occasionally and feed in coal only just what is needed. Before reaching the bottom of the grade, if it is a long one, it would be well to start the stoker so as to have a good fire and a good supply of steam when the engine begins to use the steam again.

CARE OF STOKING HEAD.—Always stop the stoker before hooking the fire as the hook might be caught by advance stroke of piston, and the stoking head or piston rod be broken. If at any time the stoking head should get a trifle loose, take off the nuts which hold it on and insert a sheet iron washer behind them to keep it tight. *Notice this every day.*

SHAKING THE GRATES.—The fireman should shake the grates often but not too much at a time. Avoid getting green coal on the grates.

DAMPERS.—Watch the dampers closely. On starting out it is occasionally best to keep the front one closed and the back one open, but over the last part of the run, or in any case where the fire is dirty and draft obstructed, it may be better to open the front damper and close the back one. The regulation of dampers must be left almost entirely to the judgment of the fireman as the varying conditions require different adjustments of the dampers.

Black Smoke.—The emission of black smoke indicates that the engine is being fired too heavily. It also indicates that coal is being wasted, and as the purpose of the stoker is to save, not to waste coal, these signs should always be recognized as an evidence of improper adjustment.

When the stoker is doing the duty it is capable of performing, the proper quantities of oxygen are admitted to the firebox to create nearly perfect combustion, which depends upon two parts of oxygen to one part of the combustible elements found in the coal and of course, a uniformly high temperature in the firebox. Therefore, black smoke may be taken as a safe guide in determining a waste of coal, resulting from too heavy firing, and the stoker should be regulated accordingly.

Tools.—With each stoker is furnished a ⅝ by ⅝ wrench, which will fit nearly all the small nuts and cap screws on the machine. The 9½-in. air pump spanner wrench, which is found on every locomotive, will unscrew the caps on the floating and reverse valve chests and will loosen the stuffing box on main cylinder, controlling engine and the rotary valve. The *thumbscrew* which holds the stuffing box on main cylinder from getting loose, is used to turn and draw out the reversing valve stem in the controlling engine. All the studs on stoker are ⅝ x 2½; all nuts are ⅝ semi-finished; all cap screws are ⅝ x 1¾.

All firemen should see that they are supplied with one 7 foot and one 12-foot hook, 2 scoops, 2 torches, 1 coal pick and 1 ash-pan scraper.

Coal.—While the stoker will handle about as large lumps of coal as can be fired by the shovel, yet all railroads forbid the firing of coal in large lumps as it is not only to the advantage of the railroad but also of the fireman, for large lumps of coal start clinkers and in the end cause more trouble to the fireman than it would be to break up the lumps. With the stoker it is particularly desirable that all lumps be broken up to a size not larger than a man's fist.

DON'T FORGET TO FILL LUBRICATOR BEFORE STARTING.

OIL.—One of the most important duties of a fireman in operating a stoker is to see *that the lubricator is feeding oil, about three to five drops per minute all the time* stoker is in use, but shut off lubricator when standing on the side track. No steam engine will run long without oil, and the stoker is no exception to the rule. Therefore we desire to impress upon firemen the fact that a lack of oil in the stoker and on all its wearing parts will not only disable or damage the stoker, but will also brand the fireman in charge of the stoker as a careless man and not fit to handle a stoker or an engine.

CARE OF STOKER AT TERMINALS.—As different customs prevail on different railroads, it is probable that the same directions for handling the stoker at terminals cannot always be followed.

Our observation, however, has led us to believe that it is better for the fireman to detach the stoker at terminals and roll it back against the coal gate, leaving it in such a position that it cannot be damaged by dumping coal into the tender, or be in the way of the men cleaning or repairing the engine.

The fireman should instruct hostlers to have a good supply of steam by the time he has reached his engine, say 100 pounds pressure or more, and he should make it a point at all times to be at his engine in plenty of time to have everything ready before time for starting. When the fireman reaches his engine he should examine the stoker carefully to see that it is all right. Blow a little steam through the pipe before connecting the stoker, and see that there is no coal or cinders in the stoker end of the disconnected pipe. Some railroad men have suggested that the hostlers should disconnect and connect the stoker at terminals. As hostlers, and particularly their helpers, would not be expected to be familiar with the stoker, we would discourage this idea as we believe it would be a source of trouble on account of misusage. Beside this, it does not take five minutes for the fireman to detach the stoker, when coming into a terminal, and he can always have it unfastened and placed back out of the way before the engine reaches the stopping place, and but a few minutes to attach stoker when ready to start out; but the fireman should insist upon the hostler or his assistants having a good fire ready for him when he reaches his engine before starting out. Always try shaker bars to see if they are properly connected and in good working condition.

ACCIDENTS.—Should an accident occur to the stoker while on the road, and you are sure that it cannot be readily repaired, cut off the steam from the stoker, loosen the connections, and if there is no room on the engine deck, run the stoker back out of the way; turn up the deflector to cover the hole in the door occupied by the trough and fasten it, firing the engine by hand until such a time as the permanent door can be put on. By removing journal caps on right-hand conveyor, the hopper can be removed and placed on back of tank. Should the engine be a small one, having no room to get the stoker out of the way, let it remain in position and fire through the small door until a stopping place is reached where it can be examined. Do not attempt to put on the regular door belonging to the engine until a station has been reached or until the conditions are such that it can be done without losing your fire. Then consider the matter very carefully as to what is best to be done.

If the stoker can be repaired in the shops of the road, have the repairs made as soon as the shops are reached, and if the repairs are of such a character that they must be made by the manufacturers of the stoker wire the shops at the first stopping place to have the necessary parts ordered. In dispatches or letters always give full information, leaving nothing to be guessed at. A few cents more expense by adding a few words more to a message should not be considered if there is the least possibility of a misunderstanding as to your meaning. In a letter, if there is any doubt of misunderstanding or misinterpretation as to what is wanted, make a sketch of the part or parts required.

In repairing the stoker, should any nuts or bolts become rusted or unremovable, soak them thoroughly in kerosene, which will, in most cases, loosen them in a short time. Be very careful not to lose any bolts, nuts, keys or other small parts, the loss of which might disable the machine.

When out on the road, make note of any parts that may become broken or out of order as soon as discovered, and upon reaching the terminal look carefully over the stoker and see if any other repairs are needed. Make it a point to have the machine in perfect condition so that it will be ready to start out on the next trip. *This is imperative,* and must be attended to before leaving the roundhouse.

Do not lose tools and extra parts committed to your care, as such losses can only be attributed to carelessness.

The following remarks concerning mechanical stokers are copied from a report by J. E. Muhlfeld, General Superintendent Motive Power, B. and O. Railroad for discussion at the seventh session of the International Railway Congress held in Washington, D. C., in May, 1905, and published in the Locomotive Firemen's Magazine of August, 1905.

Mr. Muhlfeld says:

"Since the introduction of locomotives of great power, the chief consideration in connection with the selection of men for firemen has been to procure the persons of sturdier physique, sufficiently muscled to withstand the manual labor, and who possess, in addition to their physical qualifications, the intelligence that will insure advancement to positions as locomotive engineers.

"With the usual type of locomotive furnace, grate arrangement and draft appliances, the steaming capacity of the boiler is largely dependent upon the quality of the fuel and the method of firing. More especially will this be noted where the distances are long, schedules fast, weather and dispatching conditions unfavorable, and little, or no, opportunity is given to clean the dirty fires which may accumulate on large grate areas. Under such circumstances, the better the quality of the coal used, the more satisfactory will be the results.

"Good firing requires that the proper amount of fuel be supplied to the firebox to meet the demands of the locomotive, and in the case of coal, or solid fuel, it must be placed on the grate at the proper point and time.

"With locomotives of great power, the average fireman is more a means for transferring the coal from the tender to the firebox, than an expert to insure good combustion and economy. Therefore, on long runs, it may be said that mechanical automatic stoking is not only desirable, but necessary for economy.

"In the use of liquid fuel, the apparatus for feeding the oil to the furnace may be considered as meeting the requirements of an automatic stoker but with solid and bituminous fuel, the problem is not so simple. Those mechanical automatic stokers now on the market have been designed to feed coal into the firebox in a similar manner to hand firing, and do not accomplish the results desired either as to the labor required to handle the coal, better combustion, or the prevention of large quantities of smoke. From a combustion standpoint, an underfeed type of stoker should give the most desirable performance, and as its mechanical relation with the tender would be such that the labor for handling the coal from the supply to the stoker could be reduced to the minimum, it would appear to be the proper one to devolop for locomotive purposes. By underfeeding the fuel, the fresh coal is continually introduced below the fire line, and in rising is brought to the coking stage, at which time the gases are liberated, pass upward through the fire, and are consumed to the last degree, producing as nearly as practicable complete combustion. Such a method, besides providing for a more uniform fire and consequent unvarying steam pressure, dispenses with the smoke nuisance, and there should be no waste of unconsumed fuel by loss through grates, or being carried through the tubes and ejected into the atmosphere.

"The application and practical development of a suitable design of mechanical automatic underfeed stoker in connection with the wide firebox, as now generally applied to locomotives, will be looked forward to with much interest."

THE HAYDEN MECHANICAL STOKER.

This stoker performs all of the functions of taking the coal from the tender, dividing it into small portions, and distributing it in the firebox.

To accomplish this there is first, a heavy grating placed just in front of the coal grates on the floor of the tender, beneath which the horizontal section of a coal conveyer is made to travel.

Coal dropping through this grating is taken by the conveyor and carried up on one side and thence back to the center where it drops into the tube of a screw conveyor by which it is carried to a point just back of the boiler head where it drops into a hopper.

The bottom of this hopper is closed by a valve that is capable of turning through a half revolution, and receiving a charge of coal when its opening is uppermost.

The half turn drops the coal on a shelf in front of the firebox, whence it is blown by steam jets to the various parts of the firebox with an even distribution.

The rate of feeding may be varied to suit the requirements of the engine, and quality of coal that is being used.

The receiving grate is a heavy casting having openings 4 in. x 3⅜ in. This grate lies immediately in front of the coal grates in the floor of the tender.

The conveyor tube is raised above the foot plate, thus affording ample head room beneath it and is carried by an angle arch springing from the front of the legs of the tank, and the cross piece of the conveyor.

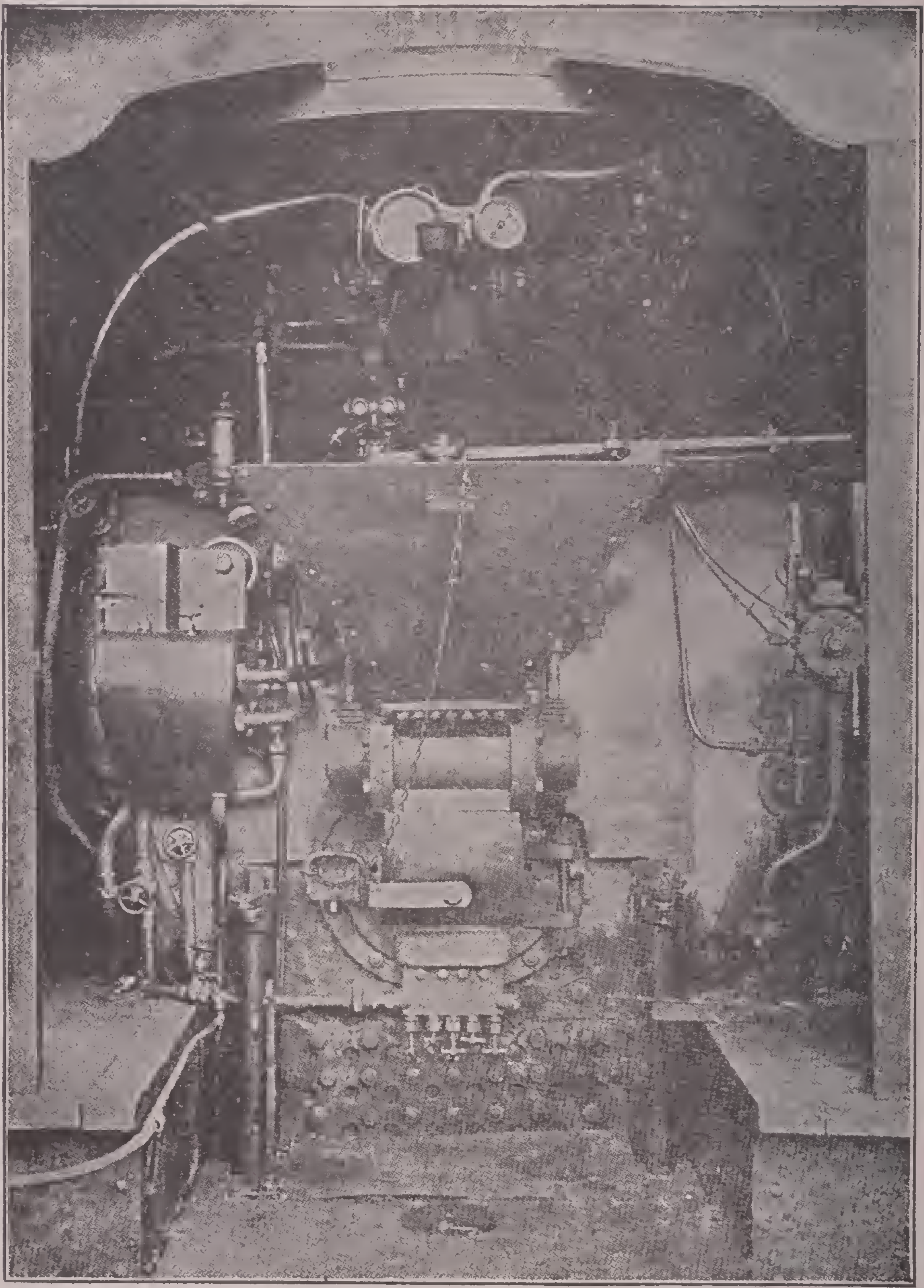


Fig. 30. Hayden Mechanical Stoker—Showing Its Application to Locomotive Boiler.

The conveyor is driven by its own engine, consisting of two 4 in. x 4 in. cylinders driving a worm, by which the speed is reduced to that suitable for the work. The hopper into which the coal drops from the screw conveyor has an upper opening of about 18 in. x 34 in. and tapers down to one of 6 in. x 10 in. at the bottom.

As the depth is about 21 inches the storage capacity at this point is 3½ cubic feet, or about 175 pounds.

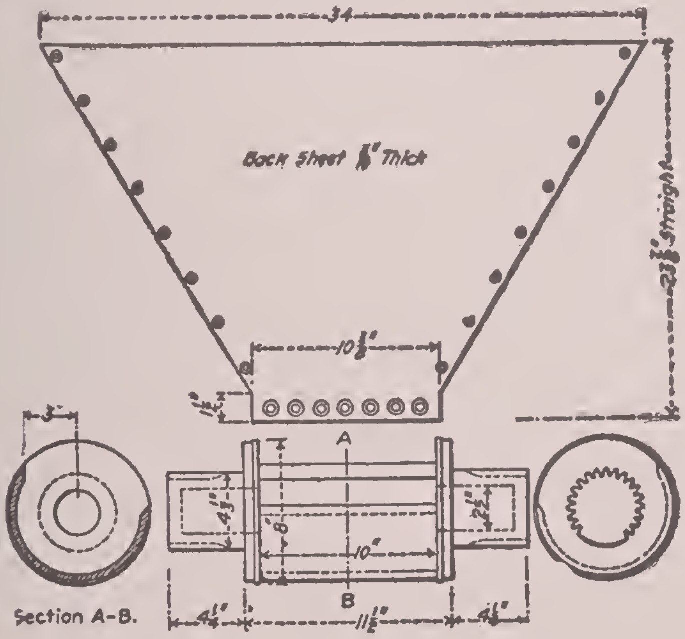


Fig. 31. Hayden Mechanical Stoker—Hopper and Coal Valve.

The charging valve is located beneath the hopper. It is in the form of a hollow shell, as shown in the illustration, and will hold about 12 pounds. The coal drops into it when the opening is uppermost. It turns on trunnions that are centered in the main casting and which are fitted with spur gears at the outer ends. These gears mesh with a couple of racks that are directly connected to the piston rods coming from the two operating cylinders *AA* Fig. 32

placed above the door and partially back of the hopper on either side. As the pistons of these two cylinders move up and down the motion is transmitted to the rack, and also to the valve, which is turned through a half revolution for each full stroke.

The steam admission, and exhaust for these two cylinders is regulated by a special valve that is driven in turn by a small two cylinder engine.

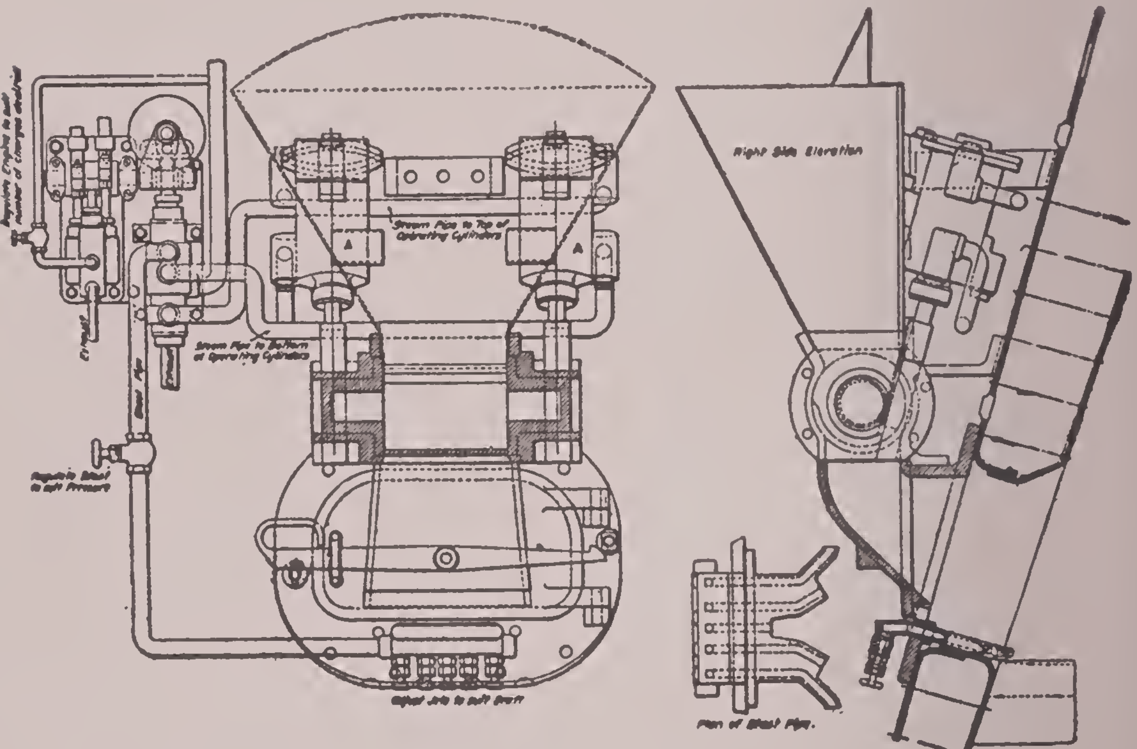

Right Side Elevation
Steam Pipe to Top of Operating Cylinders
A
A
Steam Pipe to Bottom of Operating Cylinders
Regulate Blast to suit Pressure
Plan of Blast Pipe

Fig. 32. Hayden Mechanical Stoker—Front Elevation and Section.

The engine which drives the valve of the distributing cylinders is of the two cylinder type, without eccentric or pivoted connections. The cylinders are 1½ in. bore by 1½ in. stroke of pistons. The pistons are packed with spring rings, and are solid with their rods, which latter are screwed into Scotch yokes by which rotary motion is given to the shaft.

Each yoke also serves as a point of attachment for the valve stem of the mating cylinder, so that the cranks form the eccentrics for the valve motion.

As these cranks are set at right angles with each other, when considered as eccentrics, one leads the crank, the valve of whose cylinder it controls, while the other follows it.

The valves are therefore arranged for an outside, and inside admission respectively, but, owing to the position of the cranks, can have no lap or lead, and therefore admit steam for the full length of the stroke.

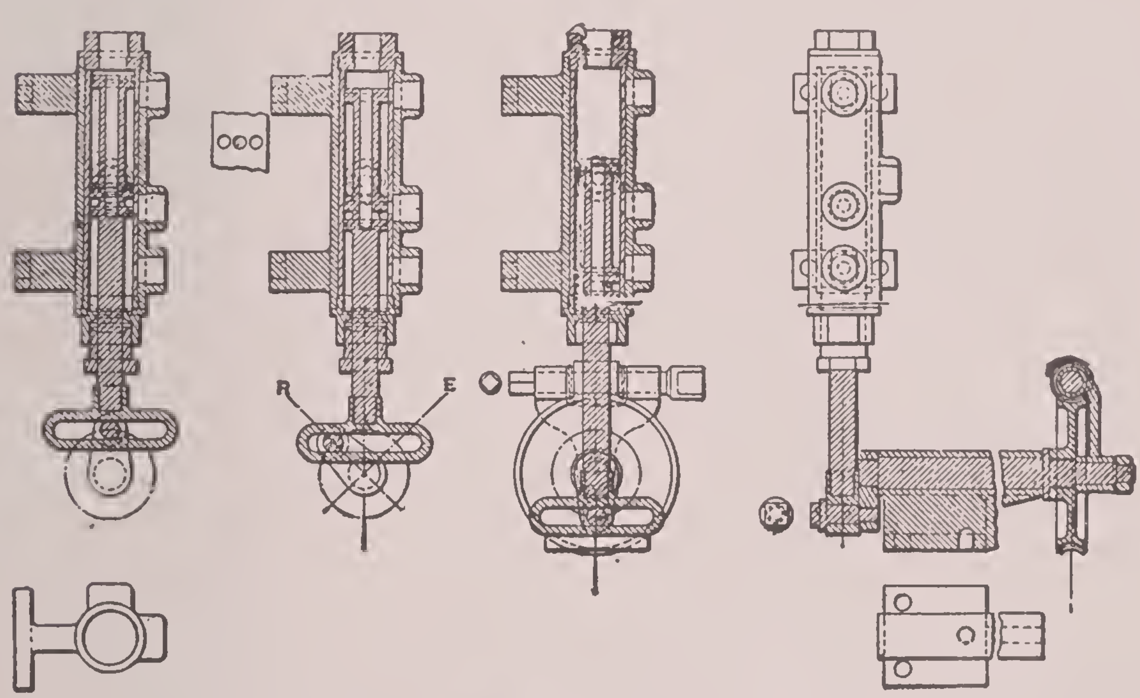


Fig. 33. Hayden Mechanical Stoker-Valve for Operating Cylinders.

In the case of the outside admission valve, steam is admitted to the upper end of the steam chest and passes down through the center of the valve to the other end, where it leaves by the side opening at B Fig. 35 to enter the space beneath the valve and be admitted to the cylinder through port C Fig. 35 when the valve has risen sufficiently to uncover it.

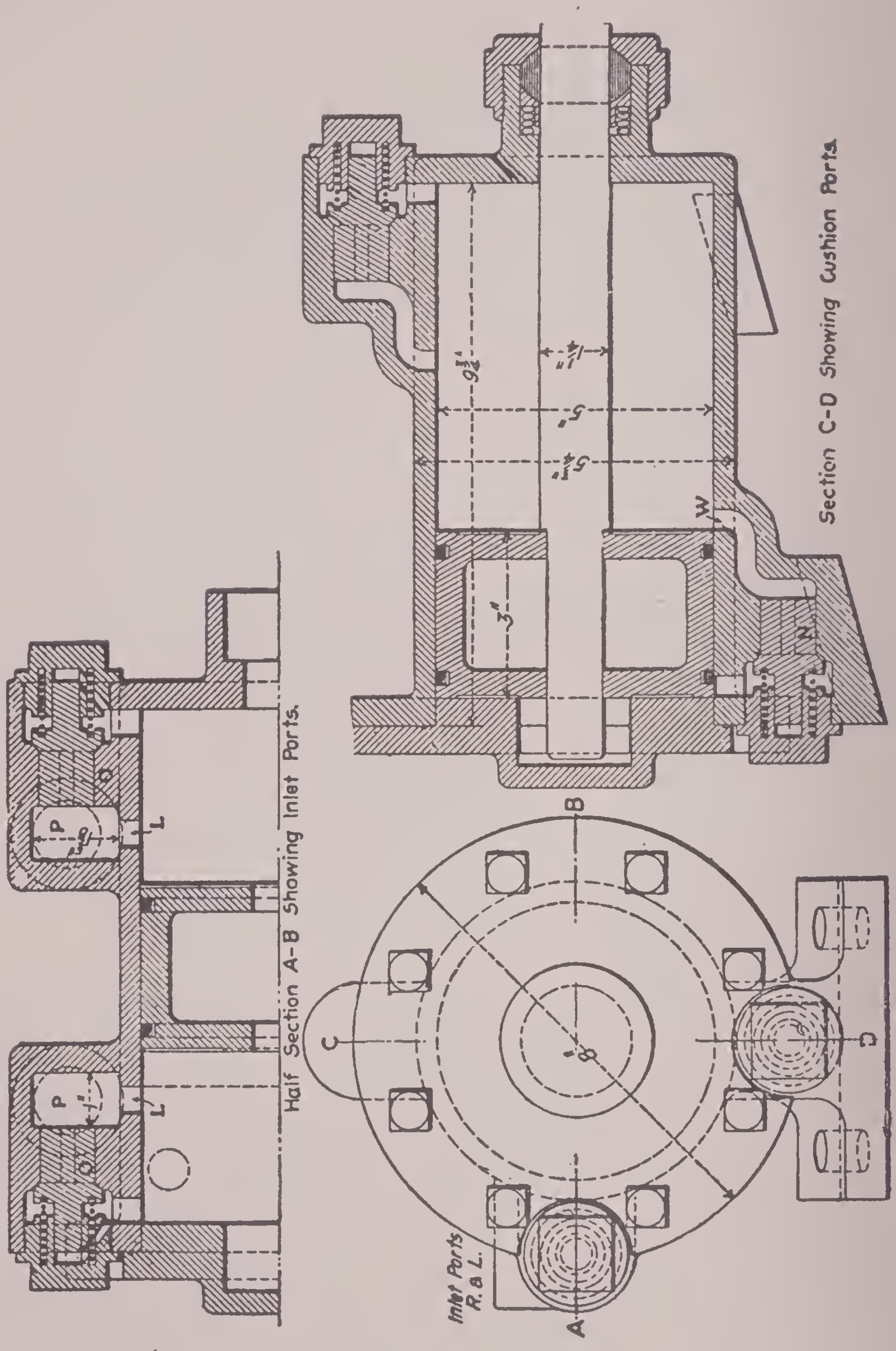

Half Section A-B Showing Inlet Ports.
Section C-D Showing Cushion Ports.
Inlet Ports R. & L.
P
P
L
L'
W
N
A
B
C
D
3"
5"

Fig. 34. Hayden Mechanical Stoker—Operating Cylinder.

For the exhaust of this cylinder the valve acts as an ordinary D valve.

In the case of the other cylinder the flow of steam with the valve of inside admission, is reversed. Steam is admitted to the center of the valve, and exhausted direct at the upper end while at the lower end it passes to the center of the valve through the side opening D Fig. 35 and thence to the upper end, and the exhaust.

The Scotch yokes are held in alignment by stems projecting downward in the usual way. These engines are very compact and measure but 17¼ inches by 7 inches by 7 inches over all. The shaft carries a worm at one end meshing with a gear of 72 teeth, on whose shaft is a crank driving another Scotch yoke that is attached to the stem of the distributing valve of the operating cylinders AA Fig. 32.

Before taking up the operation of this valve attention is called to the three functions that it must perform. It must admit steam to the two ends of the operating cylinders and exhaust it from the same. It must also admit steam to the steam jets for the propulsion of the coil at the proper moment, as it would be wasteful, and inadvisable to keep the jets open, and blowing all of the time.

Fig. 33 shows the method of action clearly. Starting with the left hand figure, and the crank at the upper point, the valve is at the extreme of its travel, and being of the inside admission type, steam is flowing out to the top of the operating or distributing cylinders, by which the pistons are forced down, and the coal valve turned to dump on the receiving plate at the door. This port, which started to open when the crank was 45 degrees from the central position on the approaching side at R,

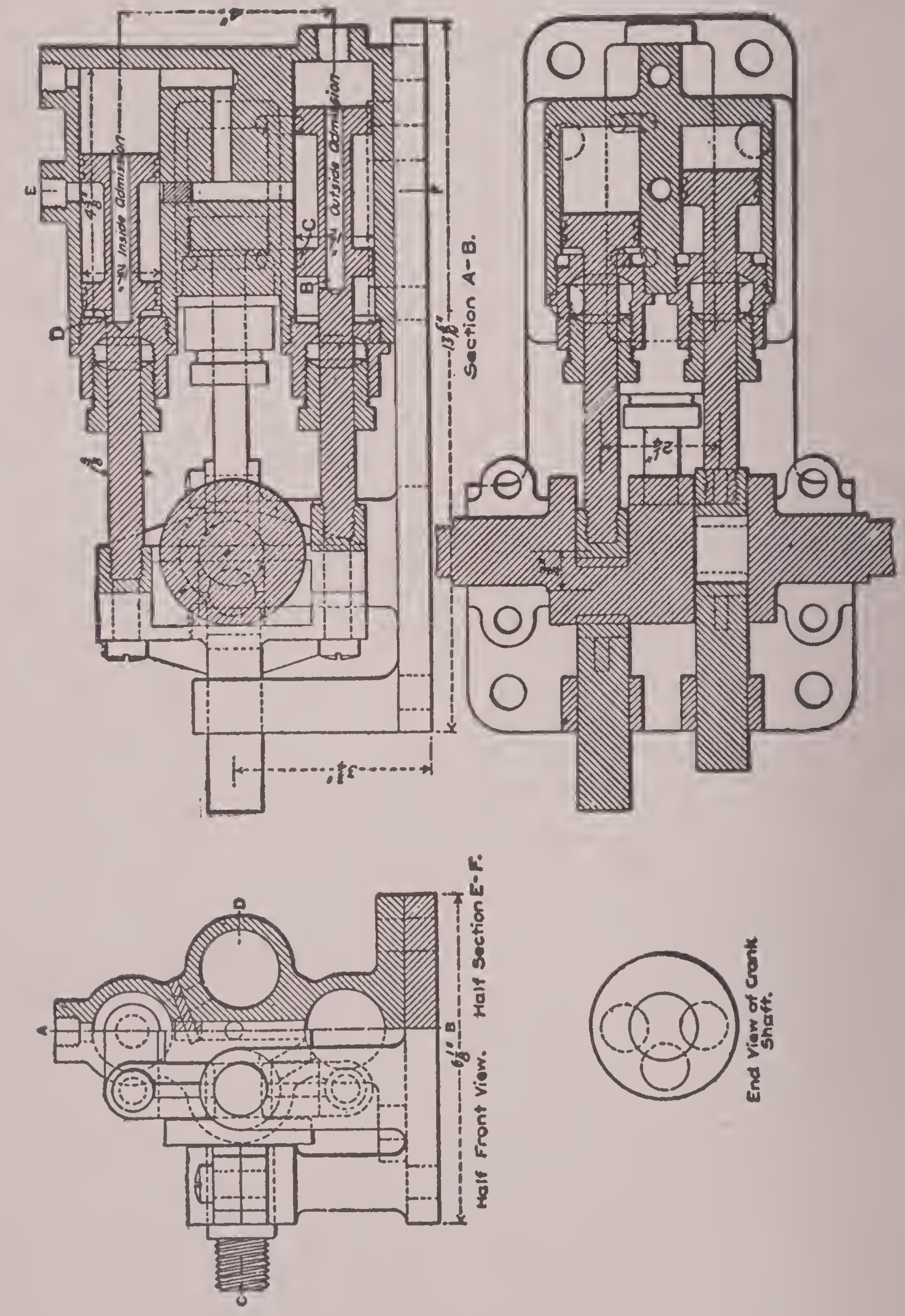


Fig. 35. Hayden Mechanical Stoker—Valve-Operating Engine.

is held open through a quarter revolution, or until the crank has reached E.

On passing this point the port is opened to the exhaust, and almost immediately the one leading to the bottom of the operating cylinder is opened to the steam, and the pistons returned to their upper position, with the coal valve set to receive a fresh charge.

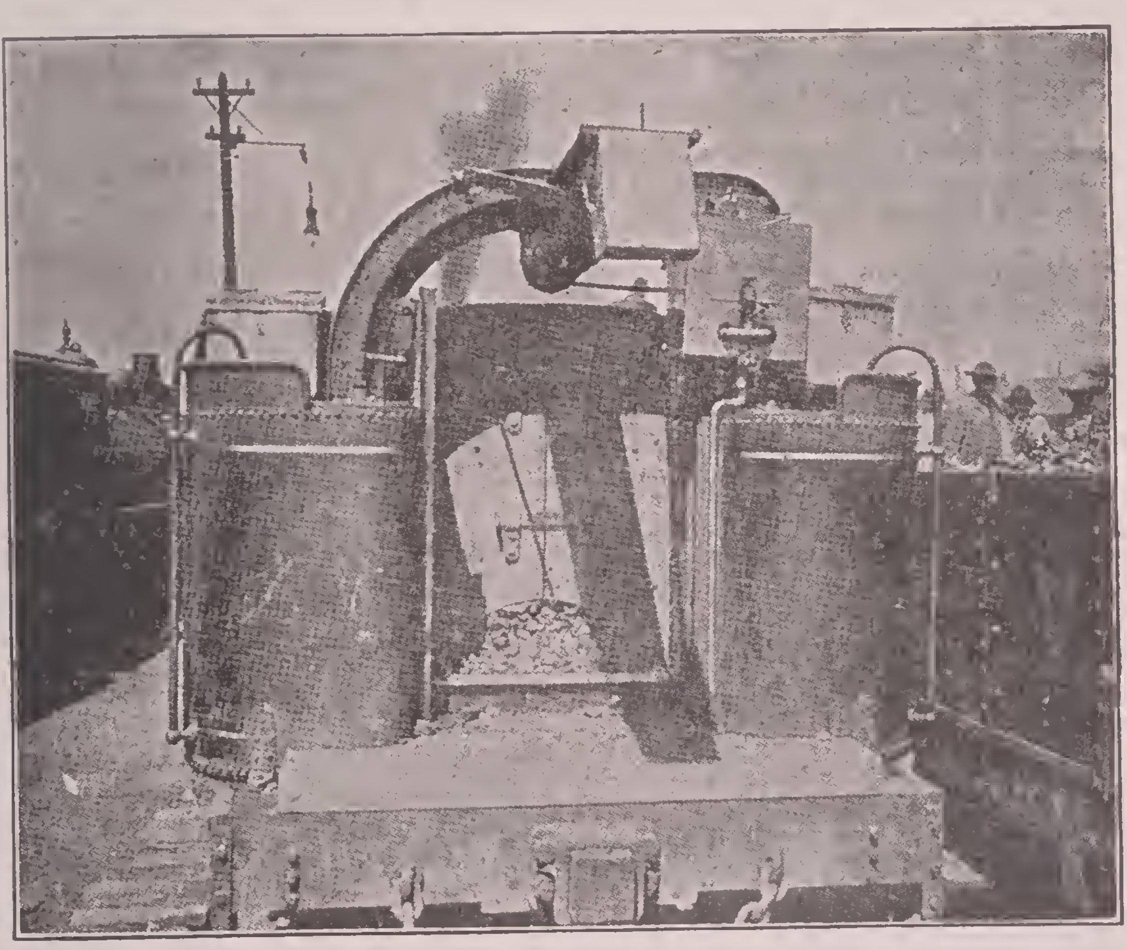


Fig. 36. Hayden Mechanical Stoker—Showing Coal Conveyor Applied to Locomotive Tender.

While the piston is down the coal valve dumps its contents upon the fuel plate, and then as the crank turns on, the valve is drawn down still lower until, just before reaching the lower center, the port of the blast pipe is opened, and the steam admitted that blows the coal out into and distributes it over the firebox.

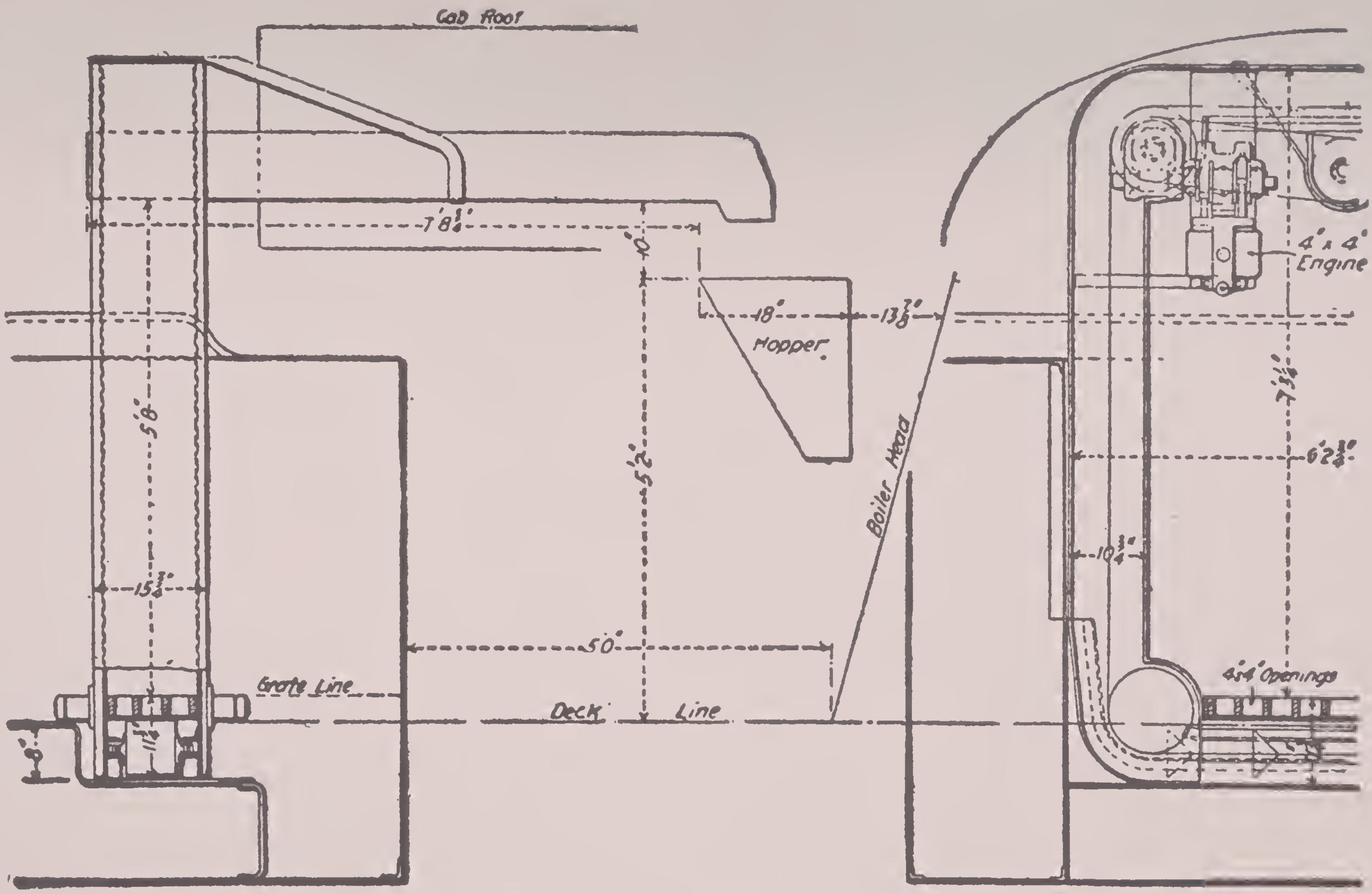
Then as the valve rises, the ports to the jet, and the lower end of the operating cylinders are closed, while that to upper is opened, and the cycle repeated.

The maximum rate of feed used upon a class H-6-A locomotive of the Pennsylvania Railroad, which is of the consolidation (2-8-0) type, is about 14 strokes per minute.

As the worm gear has 72 teeth, the speed of the small valve-operating engine is about 1000 R. P. M.

The design of the operating cylinders is worked out very carefully in order to prevent slamming and provide a proper cushion for the pistons at the end of their strokes.

This has been accomplished by an ingenious arrangement of check valves illustrated in Fig. 34. There are two sets of check valves at each end, one for the admission, and the other for the cushion. The latter are so arranged that the piston, with a stroke of 6¼ inches, travels to within 2 inches of the end, with the exhaust port at L open in front of it. This port is then covered and the insignificant resistance of the entrapped steam encountered for the next 1⅝ inches, after which the piston uncovers the port and steam is admitted beneath the check valve N, which is opened against its spring and steam flows to the top of the piston, where in the last ⅜ inch of its stroke it gradually comes to rest. The check valves OO in the steam pipes serve to admit steam above the piston and yet prevent a reverse flow into the exhaust during the period of cushioning. In studying this action it must be borne in mind that the pipes PP serve both as exhaust or admission passages according to the position



Hayden Mechanical Stoker—Side and End Elevation

Fig. 37.

of the distributing valve; also that the port L is not uncovered by the piston when the latter is at the end of its stroke. Then if steam is admitted to the upper pipe P it passes up through the check valve to the top of the piston, forcing the latter down until it passes the port L,

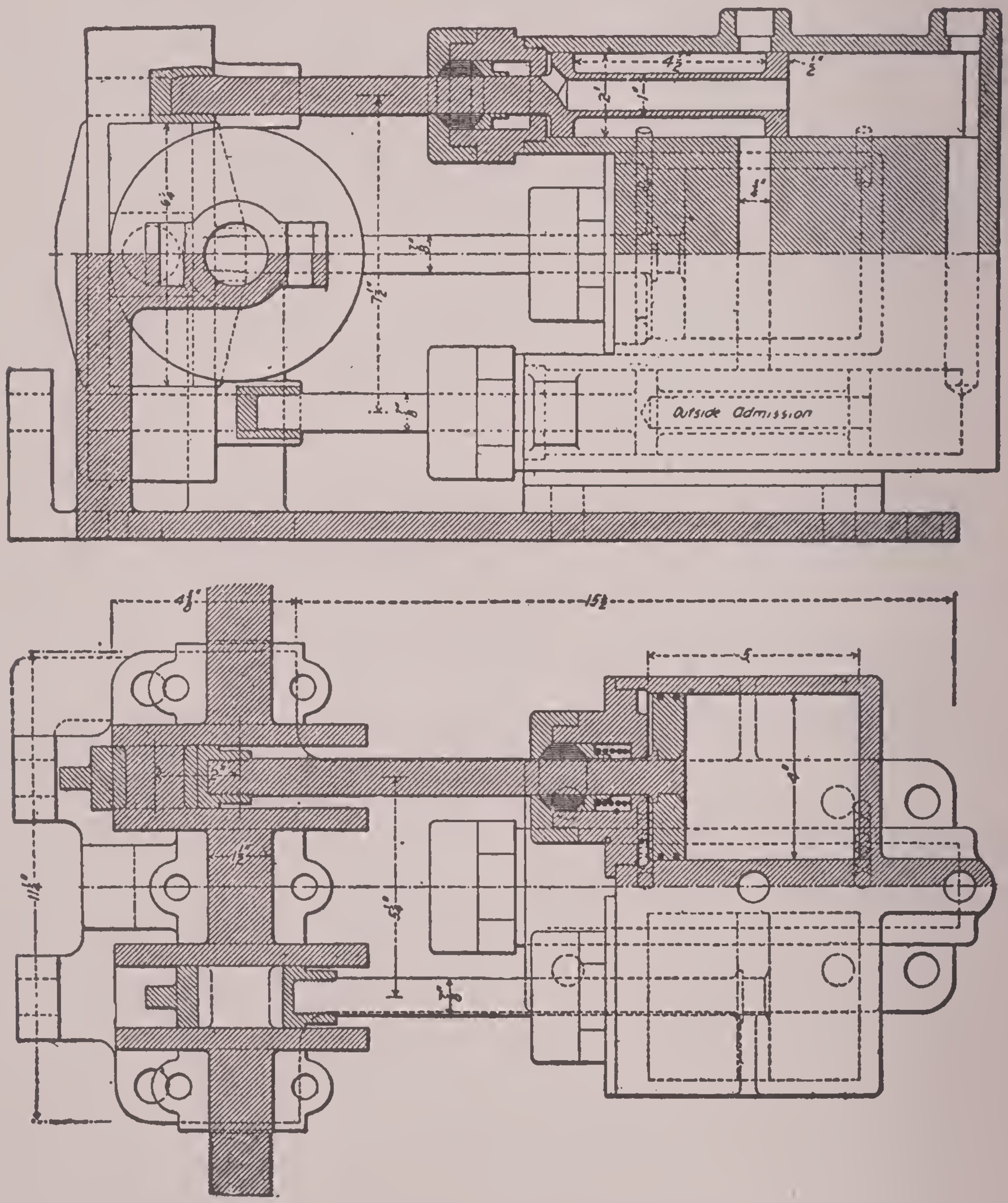


Fig. 38. Hayden Mechanical Stoker—Conveyor Engine.

when the live steam enters the cylinder above the piston by that passage. In the meantime, as the piston approaches the lower end of the stroke and steam is admitted below, the passage to the exhaust in the lower pipe P is blocked by the lower check valve O so that there can be no back flow or escape in that way. Of course the same conditions are obtained on the reversal of the stroke.

The admission of steam to these operating cylinders starts the pistons with a very rapid action. Advantage is taken of this in the construction of the coil valve. A reference to the side elevation and section will show that the lip of the valve is flush with the edge of the hopper on the boiler side but stands about 2½ inches back of it on the other side. There is thus 2½ inches of motion to the face of the valve before it begins to close the opening to the hopper. In this distance it acquires a momentum sufficient to cut through any projecting lumps of coal that may intervene and thus close with the full stroke.

With the coal delivered from the valve there yet remains the important function of its proper distribution over the grates. This is done by means of five jet nozzles shown in the plan. Steam is admitted to all of these nozzles through a pipe leading from the operating valve already described, and in which there is a valve so that the flow, as a whole, can be controlled. Each nozzle is further provided with adjusting valves by which the intensity of the individual jet can be regulated, to accord with the size of the firebox, the intensity of the draft and the quality of the coal used.

The two at the outside turn almost at right angles, and serve to deliver the coal in the back corners of the firebox, the intermediate jets throw the coal along the sides, and into the front corners, while the one in the center throws it straight ahead. The practical working will be considered later on.

The firebox door has been designed so that it can be opened at any time. It carries a chute on the back, into which the coal is delivered from the valve, and beyond this simply takes the place of the ordinary door, and can be used for hand firing in case of the disarrangement of the machinery of the stoker, or in case it is desired to rake or inspect the fires.

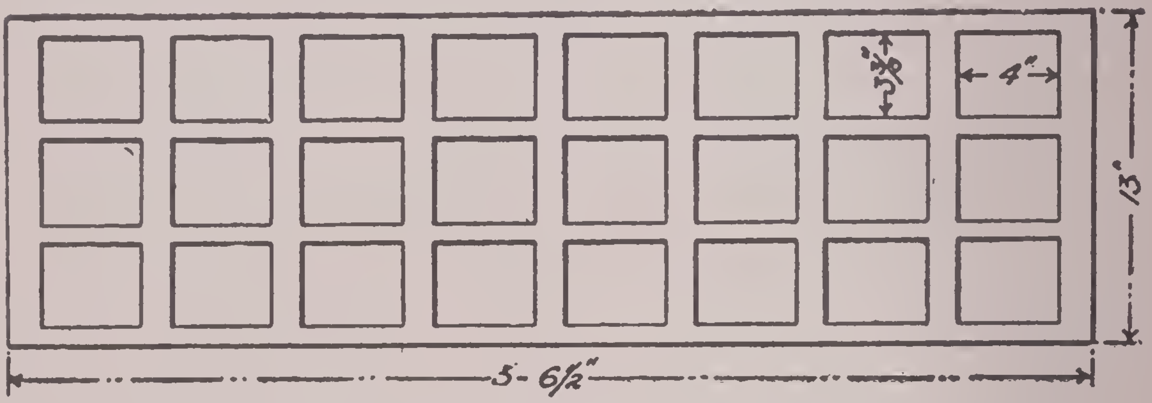


Fig. 39. Hayden Mechanical Stoker—Grating in Tender Floor for Conveyor.

Concerning its practical operations, the experience has not been extensive, but it has apparently been satisfactory. The one most important step in its development was to provide for the proper distribution of the coal,

This required a long series of experiments and when the adjustments had been made in such a manner that this distribution could be relied upon an application was made to a consolidation locomotive on the Pennsylvania lines, of the H-6-A class having cylinders 22 in. x 28 in. with a weight of 173,000 pounds upon the drivers.

Of several tests made with this engine for the purpose of determining the value of the stoker as a labor saver. and an efficient steam producer, the following record of one is given:

The distance between the two points is 100.3 miles. On leaving Columbus going east there is an adverse grade of 1%, followed by .94 and .78%, making a total up grade for a distance of 13.6 miles to Summit. from which point there is a down grade of somewhat smaller percentages into Newark, 33 miles from Columbus. From Newark to Dennison the grades are very light and short, and the road may be considered as practically level.

On the east bound trip referred to the train out of Columbus consisted of 28 cars weighing 1,281 tons. which was increased to 43 cars, and 1,839 tons at Newark. In moving about the yard the firing was done by hand in the usual manner, as the work required was intermittent and it was easier to handle the coal in this way than to start and stop the stoker at such short intervals as would be necessary.

At 12.30 p. m. the engine started with its train, and at 12.33½ the stoker was put into action, delivering coal at the rate of 14 charges per minute. Ten minutes later there was a stop on a siding to permit a passenger train to pass when hand firing was again resorted to.

The safety valves were set to open at 205 pounds and the pressure was maintained above 195 for the whole trip except on the hill out of Columbus. Here the engineman was not working the engine very hard, and the fireman, not noticing it, continued to run the stoker at full speed, with the result that a surplus of coal was thrown in and the fire deadened.

It occasionally became necessary to use the hook to level the fire, and this was done 13 times between Columbus and Dennison. The total elapsed time between terminals was 5 hours and 10 minutes, of which 1 hour and 55 minutes were on sidings, giving an actual running time of 3 hours and 15 minutes, or an average speed of 26.1 miles per hour. As a matter of fact the actual speed varied between wide limits, running from 15 to 50 miles an hour.

As the stoker was set to feed the coal faster than the requirements of the engine demanded it was necessary to shut it off at intervals in order to let the fire burn down. There was, of course, no regularity in these intervals of stopping. Sometimes they would follow one another rapidly and in quick succession; then they would be separated by wide intervals. In all, under these conditions, the stoker was standing about 22 minutes during the course of the trip. At one point the operating valve stuck for about 6½ minutes, and before it was again made operative the fireman threw 37 shovelfuls of coal into the furnace, doing it in eight firings, showing the facility with which the change from stoker to hand firing can be made.

RYAN-JOHNSON LOCOMOTIVE TENDER.

One of the hardest duties that falls to the lot of the locomotive fireman is the work of getting the coal forward in the tender within reach of his shovel, and the worst feature of this work is, that the farther along on the run he gets, the farther back in the tender the coal gets, so that by the time he is nearing the terminal, tired and almost worn out the duty of keeping the coal up in front becomes very irksome.

None can appreciate such a situation better than those who have been "through the mill," therefore two locomotive firemen, Messrs. Edward Ryan and Oscar Johnson have secured a patent for an improved locomotive tender, provided with a mechanism for moving the coal forward, thus lightening the labor of the fireman.

The following description of this device together with the illustrations is reproduced from the Locomotive Firemen's Magazine of September, 1901.

We quote: "This invention relates to improvements in locomotive tenders, the object of the invention being to provide means which can be readily operated from the forward end of the tender, the cab of the engine, or at any suitable or desired point for agitating the coal in the coal pit or moving the same forward so that it can be readily reached by the fireman without having to enter the tender to agitate the coal or move same forward.

"Locomotive tenders as usually constructed are provided with a water tank or tanks, except at the forward end of the tender, which is usually provided with a door or grate, and it often happens that the coal being used from the forward end, clogs in the rear of the pit, or is so far back, that it is difficult for the fireman to reach the same with his shovel and it thus becomes necessary for him to enter the pit, and loosen the coal or move the same forward, where it can be easily reached from the forward end of the tender.

"It is one object of our invention to provide means for obviating this labor on the part of the fireman and which can be readily operated from any desired point to loosen the coal or move the same forward in the pit.

"A further object is to provide such means with fluid-pressure-operating means controllable within the engine-cab or at any other desired point.

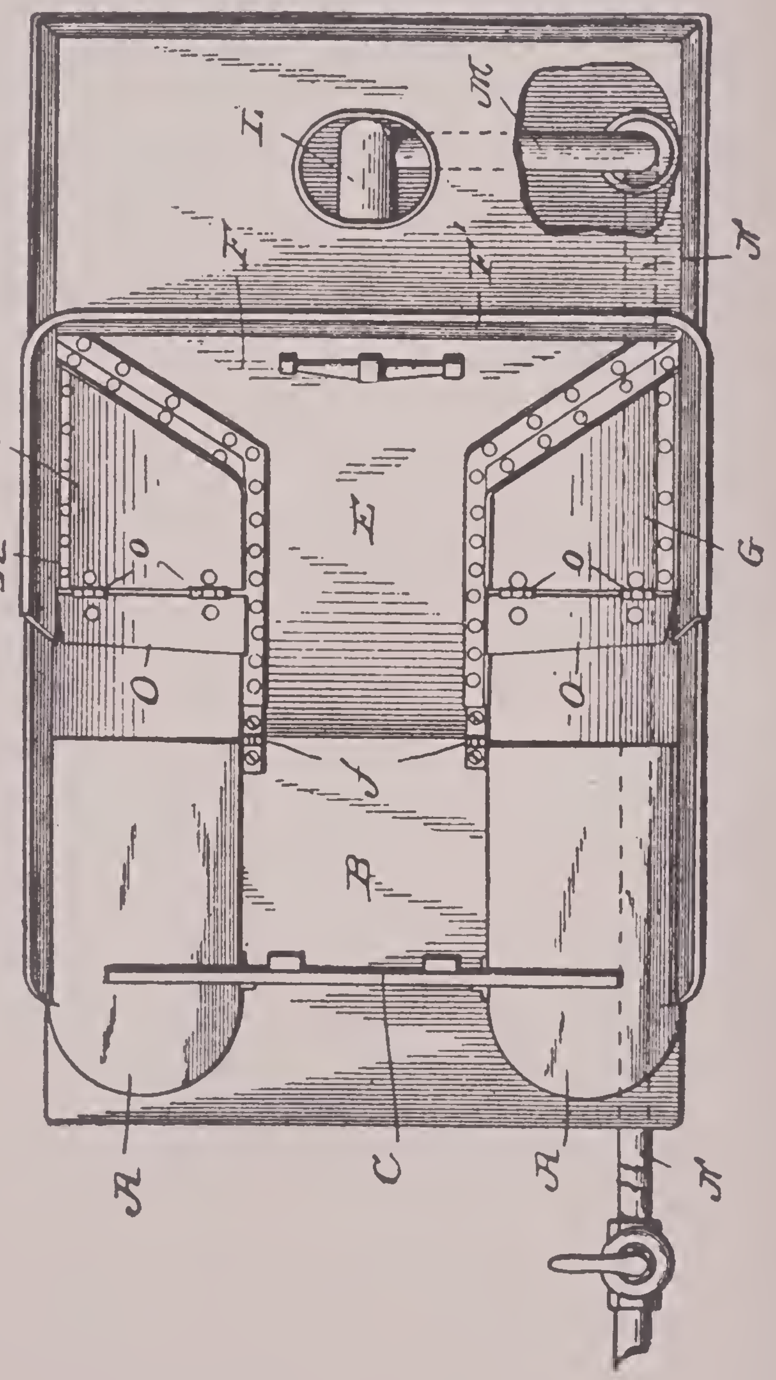


Fig. 40. Ryan-Johnson Locomotive Tender.

"A further object of the invention is to provide a tender of the usual construction with a movable back or side for the coal-pit and means for moving the said part to loosen the coal or move the same forward in the pit.

"A further object of the invention is to provide a movable side or back for the coal-pit and provide means to prevent the coal getting behind or under the back or side to prevent its proper operation.

"A further object of the invention is to provide a locomotive-tender with simple and effective means for agitating, loosening, or moving the coal in the pit.

"With such and other objects in view the invention is embodied in the novel parts, arrangement, and combinations of parts hereinafter described, and particularly set forth in the claims.

"In the accompanying drawings is illustrated a practical embodiment of the invention; but it is to be understood that the invention is not to be limited in its useful application to the construction which for the sake of illustration is there delineated.

"In the drawings, Fig. 40, is a plan view of a locomotive-tender provided with the invention. Fig. 41 is a longitudinal sectional view through the tender shown in Fig. 40, showing in dotted lines and full lines the different positions of the coal moving or loosening means.

"In the drawings we have shown only the body of a tender, which is conveniently of the usual known construction and is provided with the side and rear water-tanks or substantially U-shaped tank (indicated at A). Between these tanks or the space formed between the sides of the tanks is the coal-pit B, as is usual in the common construction of tenders, and it is believed that a detailed description of the tender-body and tanks is not necessary to an understanding of this invention.

"C indicates a gate or door at the forward end of the tender between the parts of the tank A for the purpose of preventing the escape of the coal from the pit. This gate is such as is usually employed.

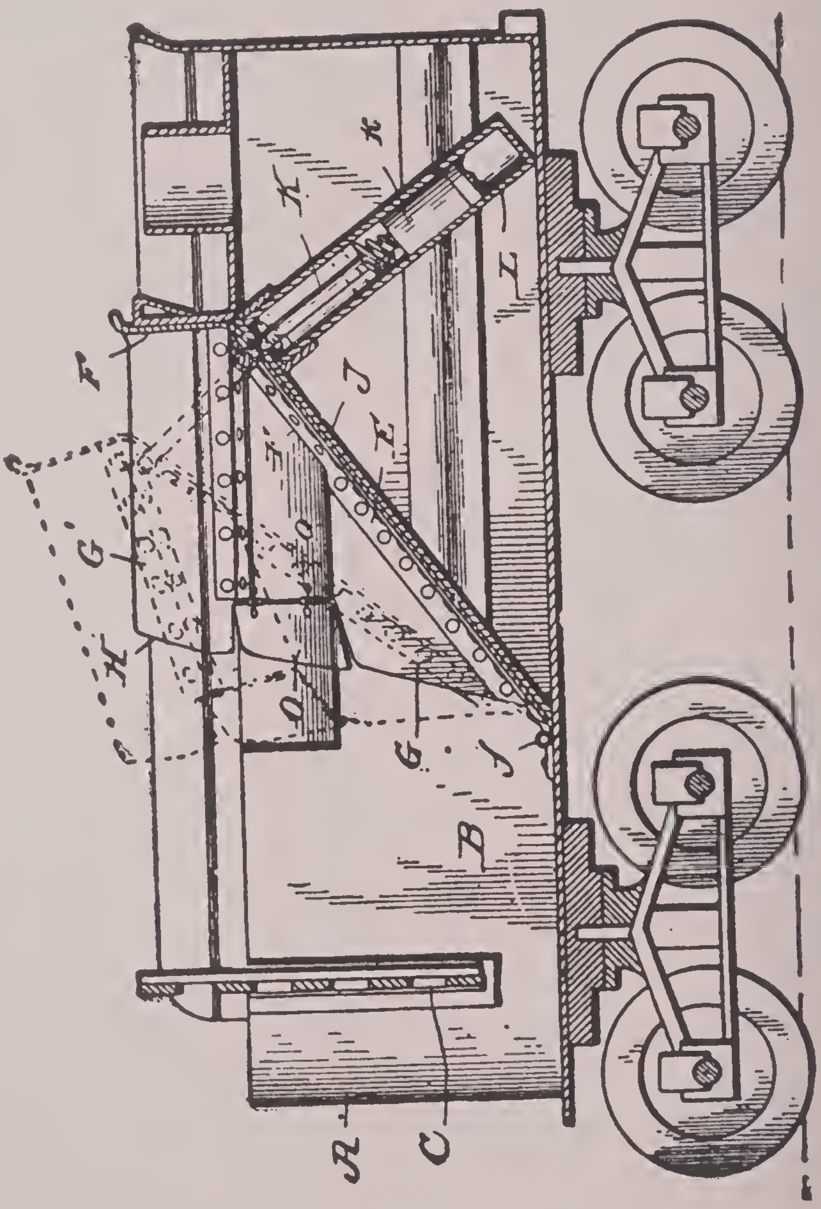


Fig. 41. Ryan-Johnson Locomotive Tender.

"E indicates a movable part, back, or side of the coal-pit which, by a movement thereof is adapted to agitate, loosen, or move the coal in the pit. Preferably this part is fashioned as a supplemental back or side for the coal-pit and has the inclined body F extending down into the coal-pit and hinged, as by hinges *f* in the bottom of the pit. Secured to the body part F are side flanges G, fashioned to conform to the vertical lower side portion and upper inclined side portion of the parts of the water-tank A. The parts F and G are preferably provided with vertical flanges F′ and G′, lying against the sides of the body of the tender above the water-tank and indicated at H. It will thus be seen that the movable means or part E is substantially the shape of the rear portion of the coal-pit and rests upon the inclined back J and sides of the coal-pit. By a movement of this part E on its hinges the coal which rests thereon is moved to loosen the same or move the same forward, and for the purpose of moving or oscillating the part E the same is shown as being provided with a piston-rod K, hinged in any convenient or desired manner to the part E and provided at its end with a piston *k*, working in a cylinder L, located beneath the part E. The cylinder is shown as being mounted within the rear portion of the water-tank. This cylinder has connected to it, conveniently at the lower end thereof, a supply-pipe M for a motive fluid—such as water, steam or air—and the pipe M may be connected by a suitable flexible hose N or otherwise to any source of fluid-pressure, such as a steam-pump or the air-brake system or reservoir of the locomotive. Suitable means (not shown) is provided for controlling the admission and exhaust of the fluid motive medium to the cylinder L to control at will the operation of the piston therein to oscillate or agitate the part E.

"It is apparent that when the part F is moved on its hinges the side flanges G move up and away from the underlying inclined faces of the water-tank, and if not provided with means to prevent the same the coal in the tank is apt to work under the side flange G and prevent the proper operation of the part E. To prevent this, each flange G is provided at its forward edge with a hinged wing O, hinged, as by means of hinges, *o,* to the flanges G. The forward edges of the wings O in the movement of the part E rest and slide on the inclined faces of the water-tank, thus always effectually closing the spaces between the wings or flanges G and the inclined faces of the water-tank.

"It will be understood that the controlling means for the motive fluid to the cylinder L can be located and operated from any desired point—as, for instance, the cab of the engine. It is not, however, believed necessary to particularly describe or illustrate any particular means for the controlling of the motive fluid."

LUBRICATORS.

In the "good old days," when tallow was the only known lubricant for the valves, it was one of the duties of the fireman on approaching a station or drifting down a hill, to seize the tallow pot and make a rush for the front end to oil the valves. This, with the weather at zero or below, was not a very desirable job, to say the least, and in course of time somebody thought out the plan of running pipes from the steam chests back to the cab, where they were fitted with a sort of funnel with a shut-off cock attached, and the melted tallow was poured in there, and the vacuum in the valve chests when the throttle was closed caused the tallow to find its way to the valve seats. But, thanks to progress and invention, tallow has been displaced by refined cylinder oil, and the tallow cup has given way to the modern sight-feed lubricator; consequently the lubrication of the valve has been much simplified, for the reason that the oil is constantly entering the valve chests drop by drop as it should. Of course the lubricator may get out of order at times, or the oil pipes become clogged, but these are troubles that are easily overcome as a rule. A few of the leading types of lubricators will be illustrated and described.

THE M'CANNA FORCE FEED LUBRICATOR.

The lubricator proper is placed on the regular standard for steam lubricators over the boiler in the cab.

The actuating valve is placed at any convenient point on the engine where reciprocating motion can be obtained.

The lever of the actuating valve is connected usually to the valve stem or rocker arm. This actuating valve is practically a rotary slide valve and is operated by a ratchet drive.

It is connected to the main air drum on the engine by a pipe connection with the air inlet shown in Fig. 44. The air ports are then connected to each side of the operating piston of the lubricator reservoir shown in Fig. 45. This piston is connected to a cross-head carrying two rods extended clear through the lubricator reservoir to another cross-head which operates the four pump plungers. These pump plungers have adjustable nuts, so that while the stroke of the operating piston is constant, the stroke of the pump plungers can be adjusted separately.

When the engine starts the reciprocating part communicates its motion to the arm of the actuating valve.

This revolves the circular valve, admitting the air to one side or the other of the piston of the lubricator proper.

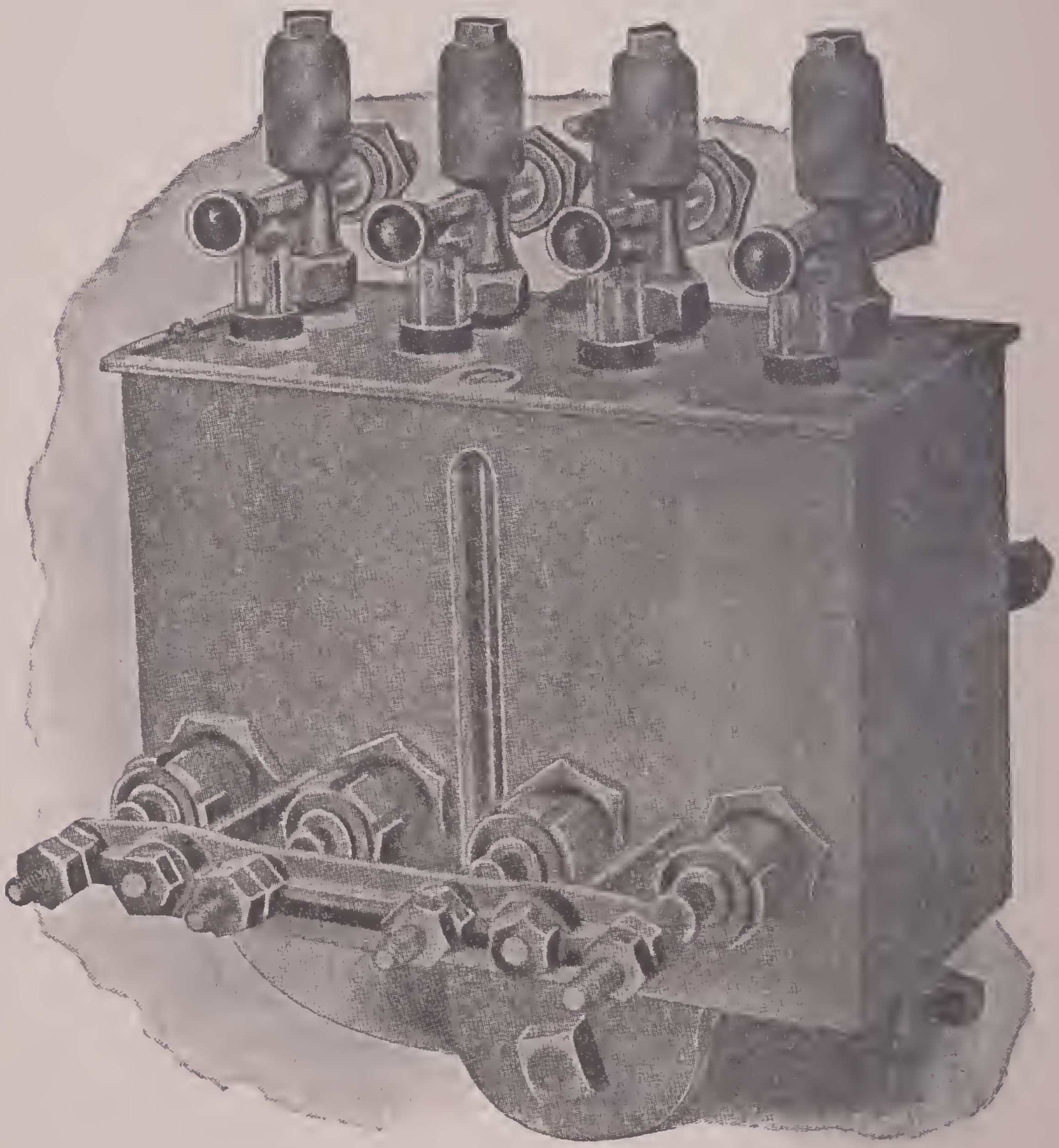


Fig. 42. McCanna Force Feed Locomotive Lubricator.

This piston operates the pump, as explained above, and the oil is pumped to the point of lubrication by positive hydraulic pressure.

At the point of lubrication is a check valve shown in

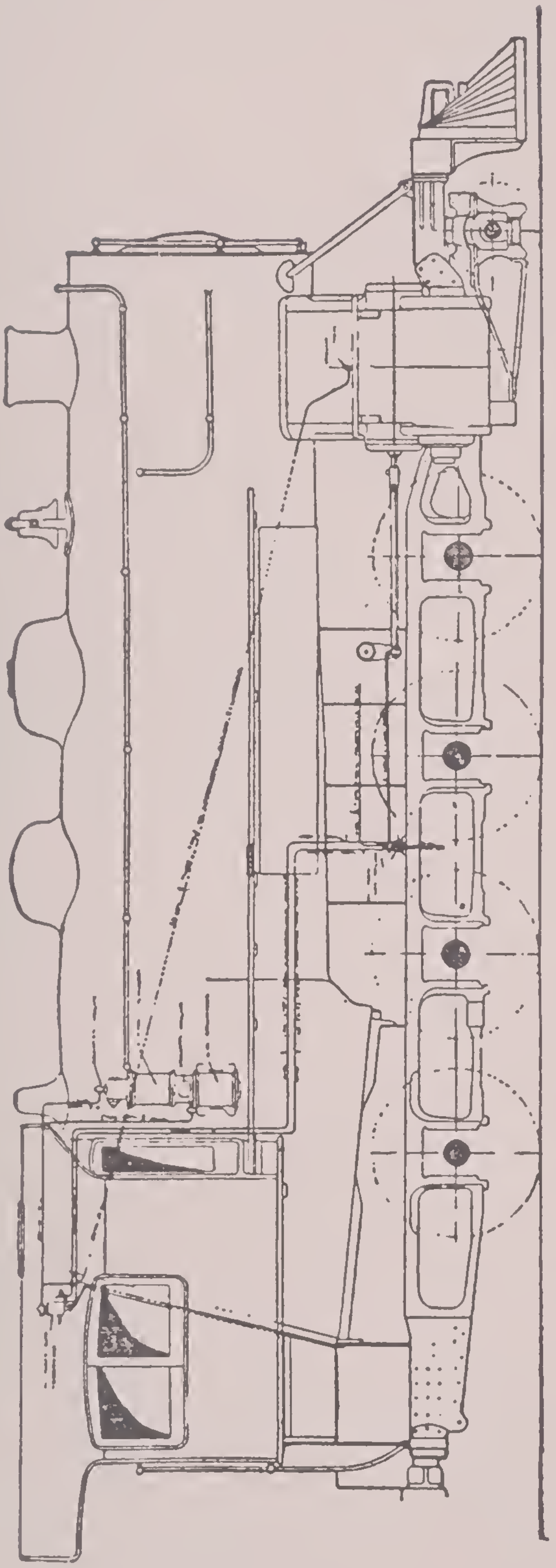


Fig. 43. McCanna Force Feed Lubricator as applied to a Locomotive.

Fig. 45, similar to that shown on the top of the lubricator, in Fig. 44, which prevents the siphoning of the oil from the pipes and also prevents the back pressure blowing the oil out of the pipes.

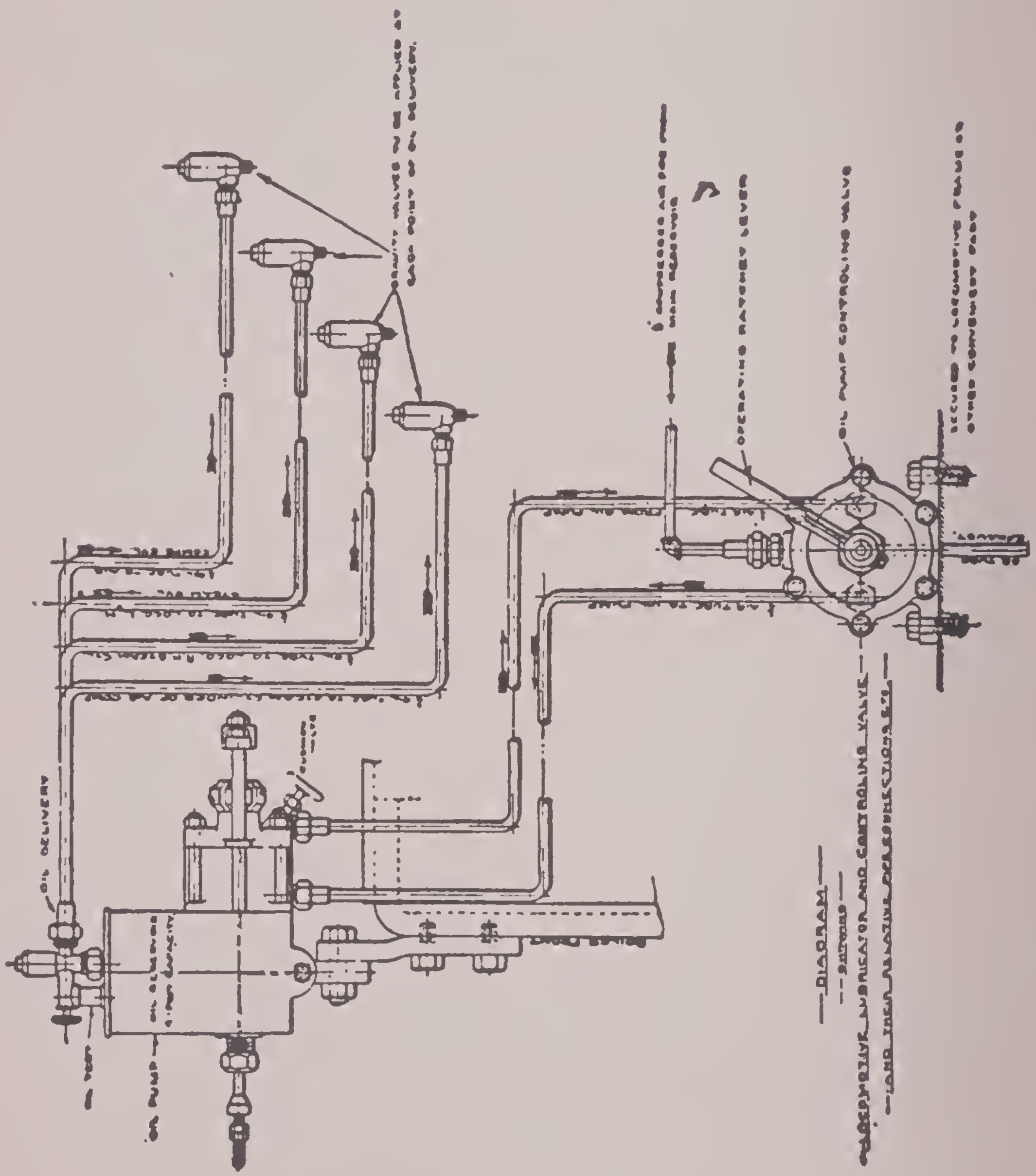


Fig. 44.

The gravity check valve is one of the principal features of the device. It consists of a cylindrical brass shell enclosing a hexagonal weight with a needle valve on its lower end closing the oil outlet. The oil to get to the point of lubrication has to raise this weight and needle valve from its seat, necessitating a pressure of about 25 pounds. It then flows through the outlet to the bearing. The weight being hexagonal and having space above and below it, and on account of its hexagonal form all around it also, any back pressure from cylinder or air pump is exerted equally in all directions and there is no tendency to lift the valve from its seat, it being held down by gravity.

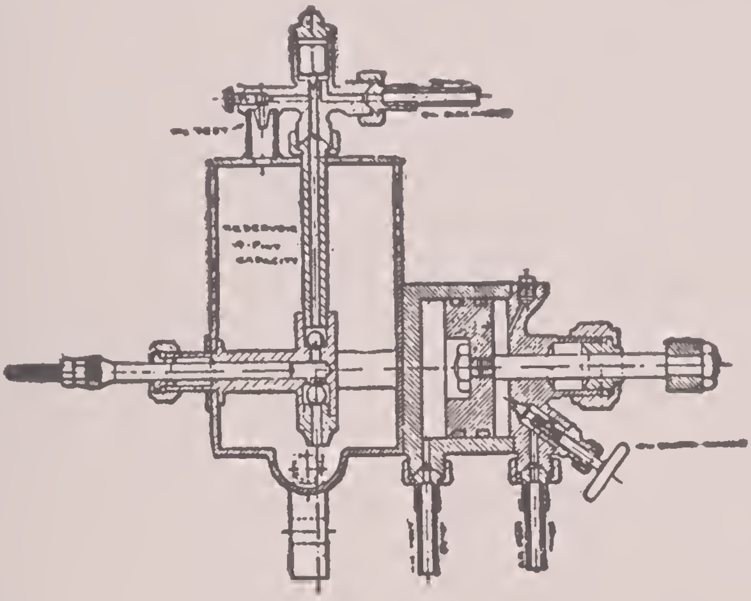


Fig. 45. Oil Pump and Reservoir—McCanna Force-Feed Locomotive Lubricator.

One of these valves is located at each pump outlet at the oil reservoir and another at each lubrication point. The one over the reservoir serves two purposes, being provided with an additional outlet, by which the amount of oil being pumped can be tested at any moment, the oil thus showing dropping back into the oil reservoir.

This method of "bleeder" test has been adopted instead of the ordinary liquid sight feed, as glycerine or water through which the oil passes in the ordinary sight feed becomes clouded after a time and requires renewal.

It will be noted that this method of lubrication absolutely eliminates any chance of broken sight feed glasses and the injury which may result from such an accident.

Lubrication, therefore, is in direct proportion to the speed, as the faster the engine travels the faster the actuating valve is revolved and the faster, therefore, the pumps are operated.

The stoke of each pump being independently adjustable, as much or as little oil can be fed to the point to be lubricated as is desired.

When the engine stops the oiling stops.

If excess of oil is wanted at any particular moment on any of the bearings for any purpose, it can be obtained by operating that particular pump plunger by hand.

The advantages claimed for this lubricator are:

Lubrication in proportion to speed.

Pure oil, free from air or steam, delivered to bearings.

Instantaneous delivery of oil against any pressure at first stroke of pump piston.

Each pump has its individual adjustment and can be regulated while lubricator is in full operation.

Elimination of all danger from broken sight feed glasses.

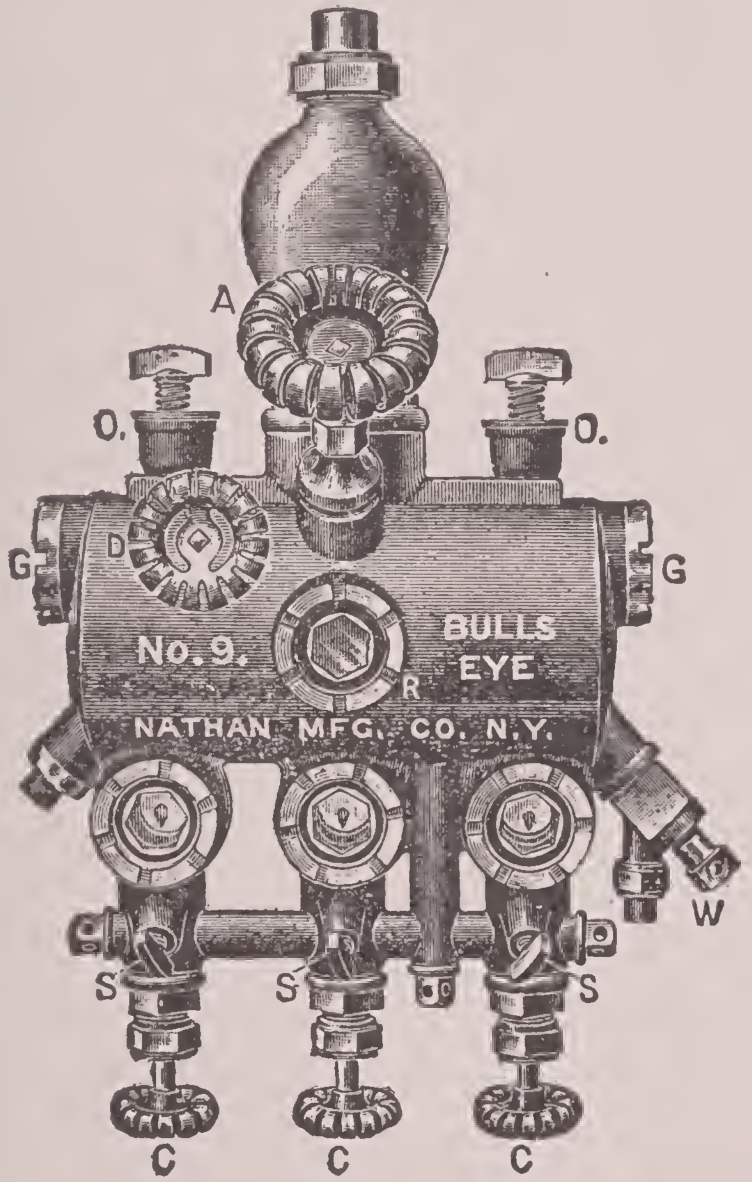
THE NATHAN NEW BULL'S EYE LUBRICATOR. Fig. 46.

General Features. The oil reservoir of the lubricator is of cylindrical form, which is generally acknowledged to be most suitable for high pressure.

The lubricator is provided with hand oilers for the cylinder feeds, and with gauge glasses which indicate when the reservoir is nearly empty.

The lubricator carries a reserve glass, packed in its casing, ready for use whenever occasion requires.

All glasses are packed in casings which screw into the body, making their removal for inspection or repairs very convenient.



Front View.
Fig. 46.

Direction for Application. 1. Secure the lubricator to boiler head or top of boiler, in the usual manner.

2. Connect for steam to fountain or turret, if large

enough, otherwise direct to boiler. The steam pipe must not have less than ¾-in. I. D. when iron pipe is used, and not less than ⅝-in. I. D. when copper pipe is used. Steam valves and their shanks must have openings fully in accordance with these dimensions.

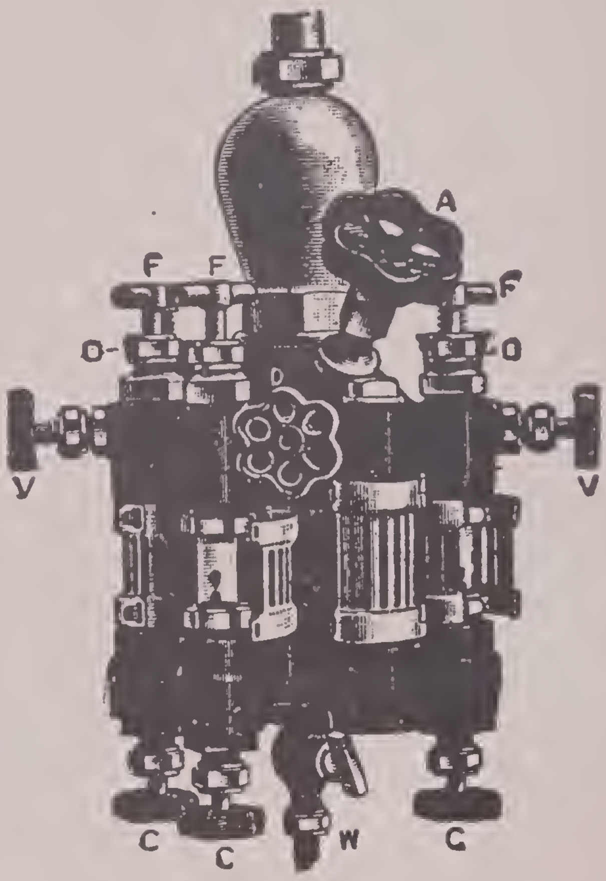


Fig. 47. New Nathan Lubricator, Front View.

3. Oil pipes must have a continuous fall towards the steam-chest, without any "pockets" in them.

Directions for Operation. Fill the cup with clean, strained oil through filling plug A, and immediately after filling, open water valve D. Open steam valve (not shown), wait until sight feed chambers are filled with water, then start and regulate the feed by opening regulating valves C, more or less, according to the feed desired.

To stop either of the feeds, close the respective regulating valve C.

To renew supply of oil, close all valves marked C and valve D, draw off water at waste cock W, then fill the cup as before, and open water valve D, immediately after filling, whether the feed is started again, or not.

To oil by hand close the steam valve. Fill the hand oilers O, open the hand oiler valves, and when all the oil has entered the tallow pipes, close hand oiler valves and open steam valve wide.

Notes. 1. Always open the steam valve before the engine begins to do any work whatever, whether the feed is started right away or not, and keep it open as long as the engine is doing service of any kind.

2. Keep the water valve D always open except during the period of filling the cup, as per directions.

3. Once in two weeks, at least, blow out the cup with steam, opening all valves wide, with the exception of the filling plug, which should remain closed.

4. When putting on the lubricator for the first time, or after it has been off for repairs, "follow up" the packing nuts of the glasses, when the lubricator gets hot, so as to take up any "slack" caused by expansion. This will tend to keep the joints tight.

THE NEW NATHAN TRIPLE SIGHT-FEED LOCOMOTIVE LUBRICATOR. *Direction for Application.* 1. Secure the lubricator to boiler head or top of boiler by a strong brace, in some such form as illustrated. Fig. 48.

2. Connect top of lubricator or dome to top of boiler or bridge pipe by copper or brass tubing, which must not be less under any circumstances than ⅝-in. inside measurement.

3. Connect the oil or tallow pipes to the union couplings on top brackets of the lubricator. The elbow on the top front bracket on right side is for the oil pipe to the air brake pump.

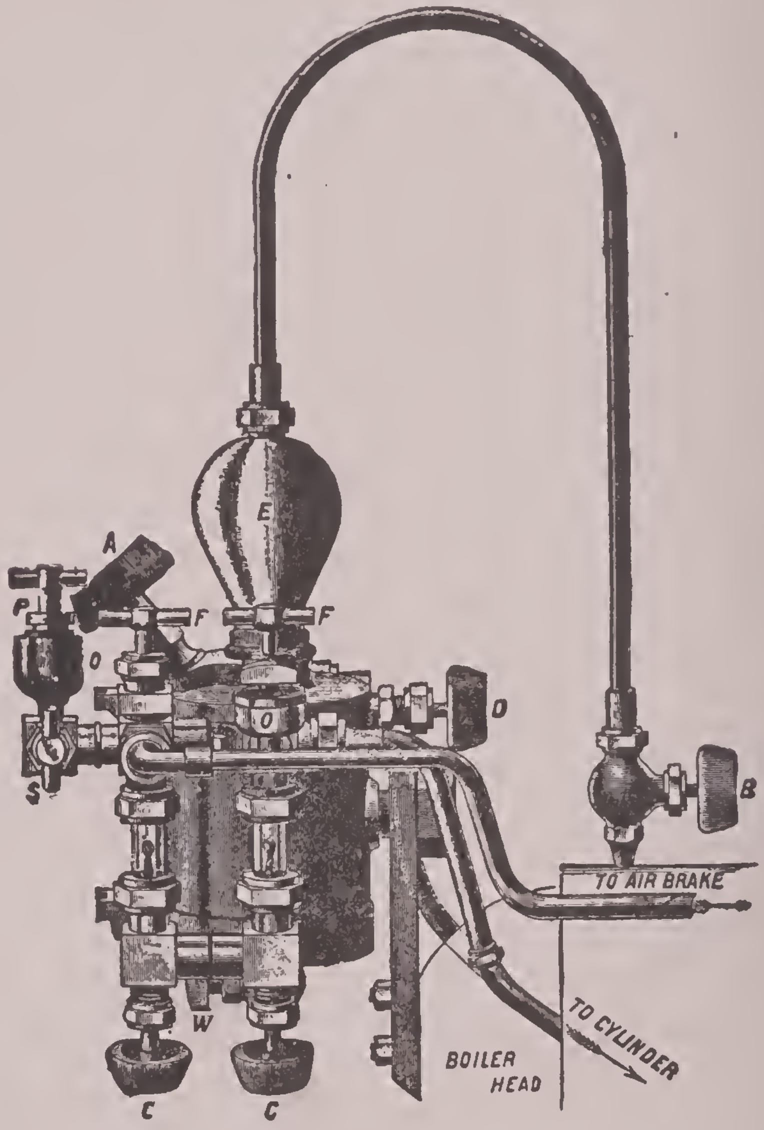


Fig. 48. New Nathan Lubricator, Side View with Steam and Tallow Pipes.

4. Remove valves from plugs over steam chests in order to maintain proper lubrication when steaming.

The sight-feed and gauge glasses of these lubricators are provided with proper shields and protectors, to prevent the flying of particles in case of a broken glass.

Directions for Use. Fill the cup with clean, strained oil through the filling plug A, and immediately after filling, open the water valve D. Open the steam valve B, and start to regulate the feed by opening the regulating valves C more or less, according to the quantity desired.

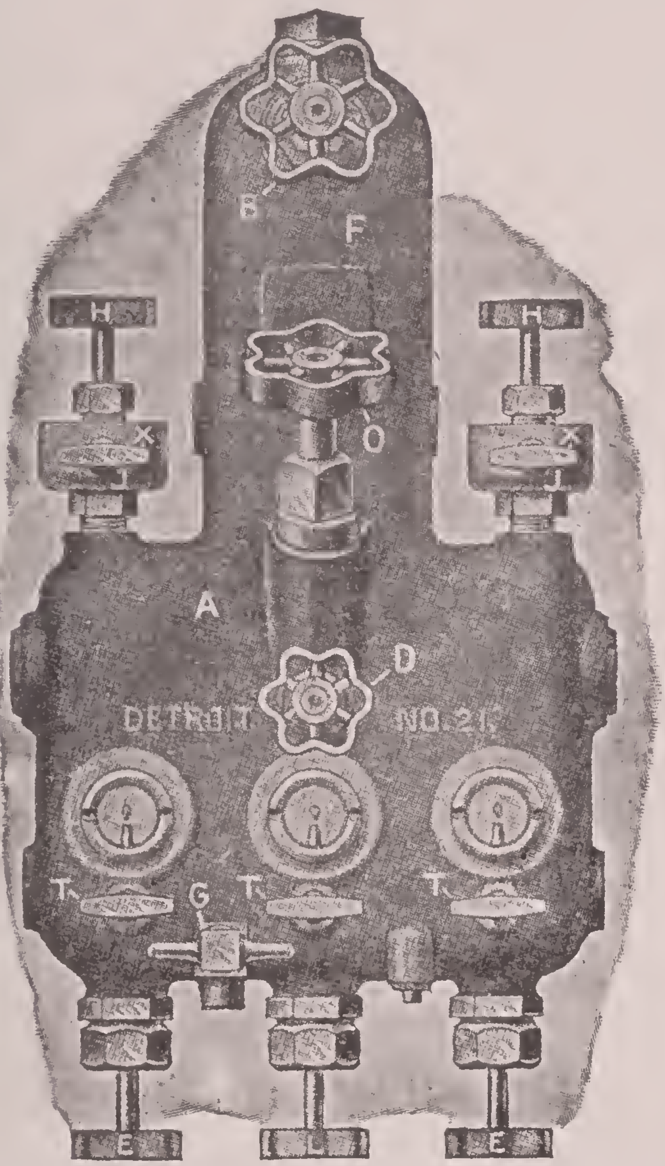


Fig. 49. The Detroit No. 21 Locomotive Lubricator.

To stop either of the feeds, M close the respective regulating valve C.

To renew the supply of oil, close all the C and D valves, draw off the water at the waste-cock W, then fill the cup as before and open the water valve D immediately after filling whether the feed is started again or not.

Notes. 1. Valves F F F must be always kept open except when one of the glasses breaks. In such case close valves C and F belonging to the broken glass and use the auxiliary oiler O on that glass on down grades, as a common cab oiler.

The breaking of one glass does not interfere with the proper function of the others.

2. Always open the steam valve before the engine begins to do any work whatever—whether the feed is started right away or not, and keep it open as long as the engine is doing service of any kind.

3. Keep the water valve D always open except during the period of filling the cup, as per directions.

4. Once in two weeks at least, blow out the cup with steam; open the valves wide, with the exception of the filling plug, which should remain closed.

THE DETROIT NO. 21 TRIPLE FEED LOCOMOTIVE LUBRICATOR, with auxiliary oilers and gauge glass. Fig. 49.

This device is simple in construction and simple of operation.

The oil is maintained at a uniform temperature and will not chill.

The feed is absolutely regular.

All feeds are visible from two sides.

An additional valve has been placed at the top of the lubricator to control the supply of steam from the boiler, making the device self-contained.

Directions for Operating. When the lubricator is first applied, blow out thoroughly, then close all the valves.

To Fill. Remove filler plug O and fill the reservoir with clean strained oil.

Steam Valve. The regular boiler valve should be left wide open, and the steam valve B at top of condenser must also be kept open wide while the locomotive is in service.

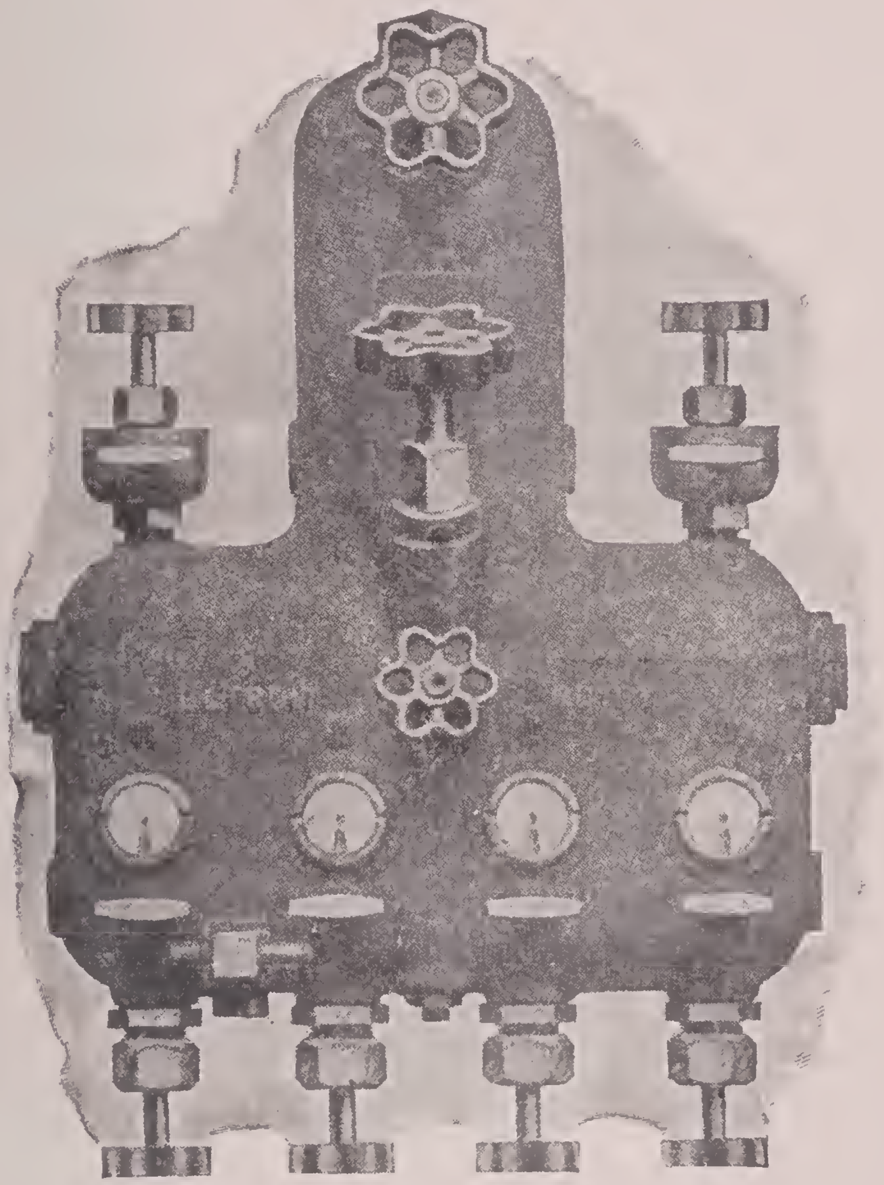


Fig. 50. Detroit 4-Feed Lubricator.

To Start Lubricator. 1. Be sure that the regular boiler valve is open. Then open steam valve B at top of condenser gradually until wide open and keep wide open while lubricator is in operation. Allow sufficient time for condenser and sight-feed glasses to fill with water. 2. Open water valve D. 3. Regulate flow of oil to right and left cylinders by valves E E, and to air pump by valve L.

To Operate Auxiliary Oilers. See that valve H is closed. Then open valve X and fill body of oiler. Close X after filling and open valve H.

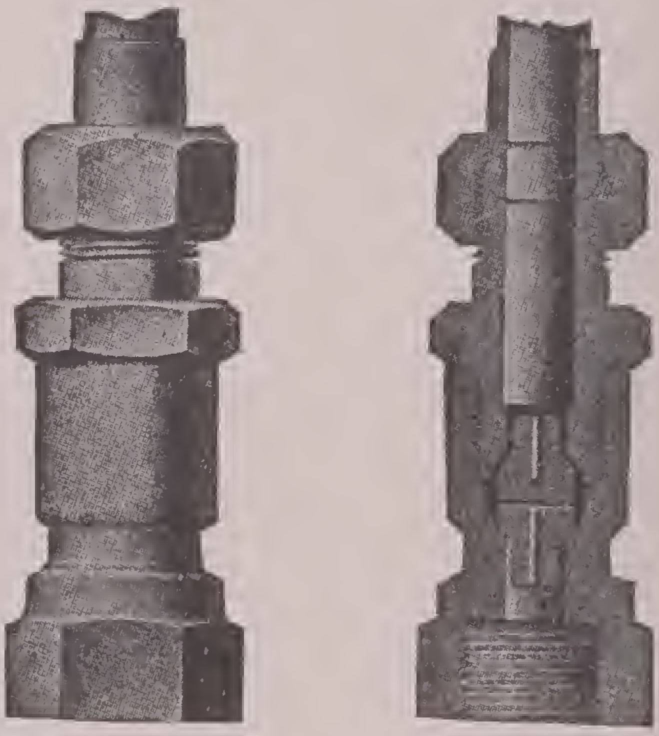


Fig. 51. Automatic Steam Chest Plugs and Valves.

To Refill. Always close valves E E and L in advance of valve D. Open drain plug G, then filler plug O. Refill and proceed as before.

Immediately after filling the lubricator do not fail to open the water feed valve D, in order to prevent any excessive pressure due to the expansion of the heated oil.

Getting New or Rebuilt Locomotive Ready for Service. In getting a new or rebuilt locomotive ready for service, disconnect oil pipes at steam chest, and blow out thoroughly both oil pipes and automatic steam chest valves; also disconnect coupling to air pump and see that choke is free.

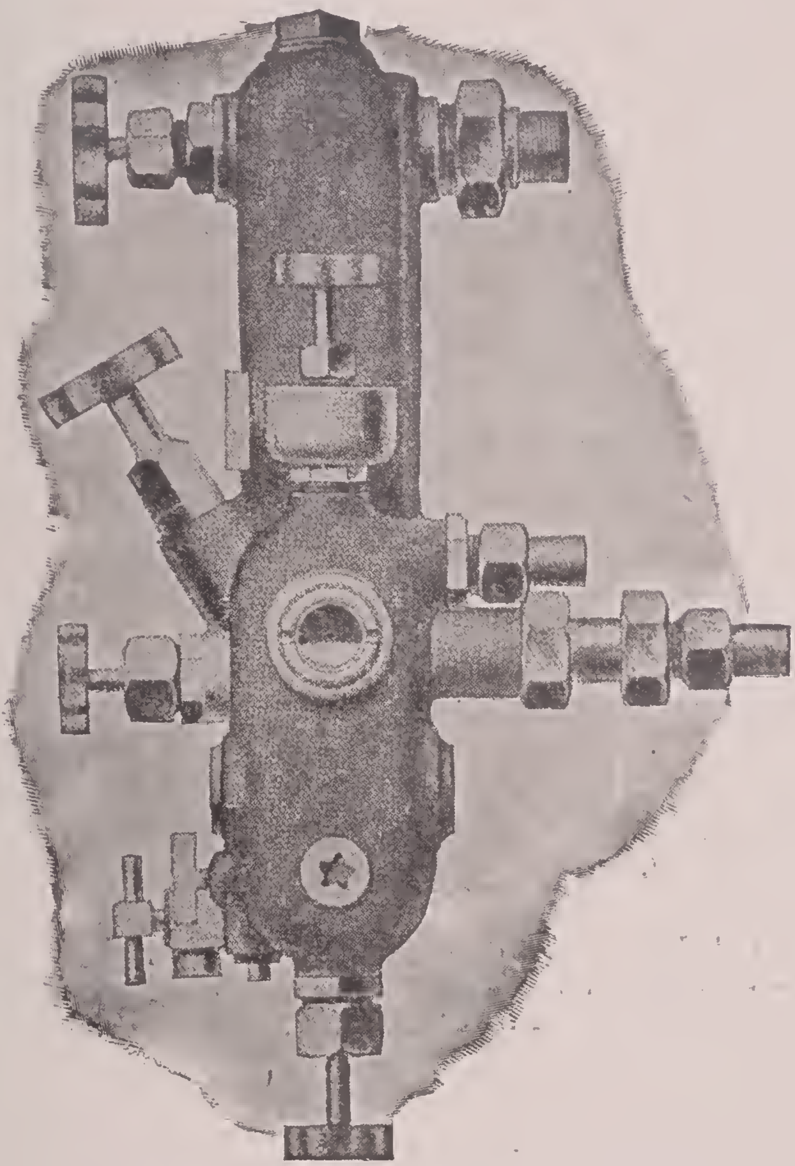


Fig. 52. Detroit No. 21, Side View.

Steam for lubricator should be taken from turret if large enough, or from dome through an independent dry pipe of 1-in. iron pipe size or its equivalent.

When the No. 31, or four-feed lubricator is applied to the Vauclain type of compound, the two outer feeds are intended for high pressure cylinders. Two automatic steam chest plugs are furnished, stamped and tagged "H. P.," having 3-32-in. chokes. The two remaining feeds lead to the low pressure cylinders, and two other automatic steam chest plugs are furnished to be used with them, stamped and tapped "L.P." and having 1-16-in. chokes.

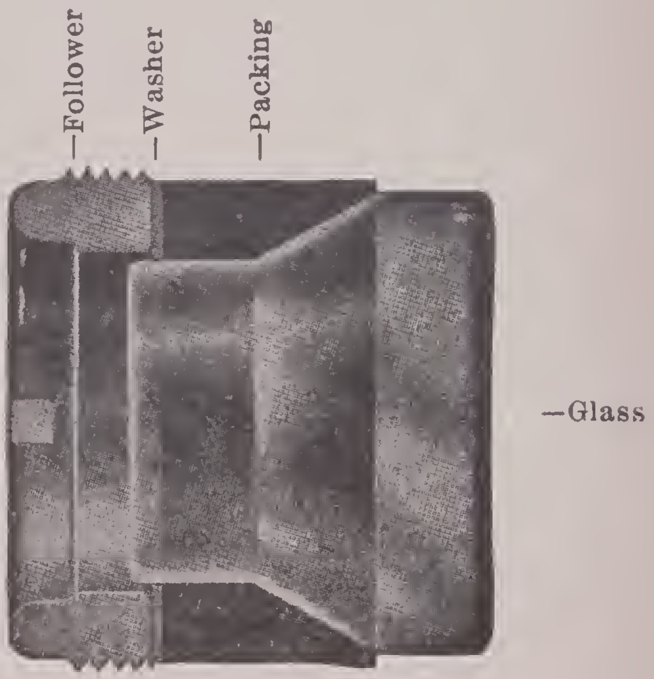


Fig. 53. Detroit Lubricator Glass and Method of Packing—Direction of Pressure Indicated by Arrow. The Higher the Pressure the Better the Joint.

Helpful Hints. *Blowing Out.* Blow out lubricator once a week.

Filling. If there is not sufficient oil to fill the lubricator, always use water to make up the required quantity. This will enable the feeds to start promptly.

The steam valve B must be opened wide when the locomotive is in service to allow condensation to enter the condenser; otherwise condensation will be diverted to equalizing tubes. The feeds will gradually slow down as the water of condensation decreases.

When getting a new or rebuilt engine ready for service or when using soda ash boiler compounds, or when running in bad water districts, impurities will be carried over into the condenser and will gradually accumulate at base of water valve until the water is completely shut off. While this is taking place the feeds are affected the same as before described, and when this passage is finally closed by the sediment feeds will cease altogether.

How to rectify while locomotive is in service: Close all feeds and water valve; open drain cock 2105 and allow about ½ pint of water to drain off; close drain cock and open water valve quickly. The condenser pressure will then force this sediment into bottom of lubricator, where it can be blown out in the usual manner, when the lubricator is empty.

Do not screw up too tightly the feed glass follower, as this will only serve to injure the packing. There is no danger of leakage at this point, as the glass and packing are so designed that the greater the pressure the better the joint.

Small Drop of Oil. The cause of a small drop of oil or the variation of size of drop during a trip. In alkali, salt water or oil well regions through which railroads pass, the water supply becomes impregnated with saline matter. This saline matter is carried over in the lubricator mechanically by the steam, so that the water in the sight feed glasses contains considerable of it and the amount increases as the locomotive proceeds on the trip until it crystallizes around the feed cones, thus gradually diminishing the size of the opening for the drop. Should the engineer undertake to force the feed it will result in the oil flowing in a very slender stream, scarcely perceptible. If this condition is not corrected the salt crystals will completely close the feed cone orifice.

How to Rectify. Close all feed stems; open all sight feed drain stems and blow out thoroughly. The action of the stream on feed cones will dissolve the salt crystals. Allow reasonable time for condensation; start the feeds, and the drop of oil will be normal.

Air Bound. This condition is almost invariably brought about whenever it becomes necessary to fill a lubricator on the road. The temperature of a lubricator at such times is very nearly that of the steam pressure temperature. Sometimes the water feed valve seat may leak, and in order to fill the lubricator in this heated condition it is found necessary to shut off all steam pressure to the lubricator, including the air pump, and owing to the high temperature of the condenser the water flashes into steam, practically emptying the condenser and feed glasses of all water. The oil reservoir being very hot, the oil expands rapidly and the filler plug is usually put in before the reservoir is full. The steam and water pressures are hurriedly turned on and the feeds are opened before sufficient time has elapsed for sufficient condensation to accumulate. The feeds will not respond under such conditions, because the positive and negative pressures have equalized, and the lubricator is said to be air bound.

How to Overcome. Open all feeds and any one of the sight feed drain stems. This will allow the water in the oil tubes and the air occupying the highest space in the oil reservoir to escape to atmosphere.

PRINCIPLES GOVERNING THE ACTION OF LUBRICATORS.

The following clear explanation of the action of the sight feed lubricators is reproduced from the Jan., 1906 issue of the Locomotive Firemen's Magazine, and may prove of benefit to beginners at least.

We will assume that we have an ordinary sight-feed lubricator with a condensing chamber on top of the oil reservoir, a partition between the condensing chamber and the oil reservoir, a pipe or passage leading from the base of the condensing chamber to near the bottom of the oil reservoir, a pipe or passage for oil extending from or near the underside of the partition downward to near the bottom of the oil cup and branching out to the feed valves under the sight-feed glasses. When the cup is filled with oil and the valves opened, steam enters the condensing chamber and condenses. The water flows down the pipe and, being heavier than the oil, the oil is floated to the top of the oil reservoir and fills the passage to the sight-feed valves with oil. Now we have a pressure on the oil equal to the pressure of steam in the cup and the weight of the water in the pipe and condensing chamber, forcing the oil through or to the sight-feed nipples. (This would occur if the equalizing tube on a lubricator was stopped up and the glass was broken.) It does not matter whether the equalizing tubes are inside of the condensing chamber or outside, the principle is the same; the equalizing tubes extend from near the top of the condensing chamber to the top of the chamber above the sight-feed glass and exert a pressure downward on the water in the glass; hence, are called equalizing tubes, because they equalize the pressure in the lubricator. The choke plug is a small opening which only allows a small amount of steam to escape into the oil pipe leading to the steam chest, but it carries any water that may accumulate above the level of the choke plug into the oil pipe. Now you will readily understand why they are called equalizing tubes; when the feed valve is open a drop of oil will form in the nipple of the sight-feed glass and, on account of its being lighter than the water, it rises to the top of the water in the chamber above the sight-feed glass and is carried through the choke plug, forced into the oil pipe and to the steam chest by the steam from the equalizing tube when the pressure at the lubricator end of the pipe is greater than the pressure at the steam chest end of the pipe.

MECHANICAL BELL RINGERS.

Locomotive bell ringers are no longer a luxury—they are a necessity.

The duties of the fireman, who used to ring the bell, have increased with the increased size and speed of locomotive. A man furnishing coal to an up-to-date fire-box has little time to do much else when the machine is in motion.

The engineer's attention must not be taken from his work—cannot be with safety.

The Samson Bell Ringer, Fig. 53a, lays claim to the following merits:

Has no packed joints except the piston, which has heavy, leather packing.

Valve is a plug cock held to seat by a coiled spring.

Economical of air, because weight of bell compresses

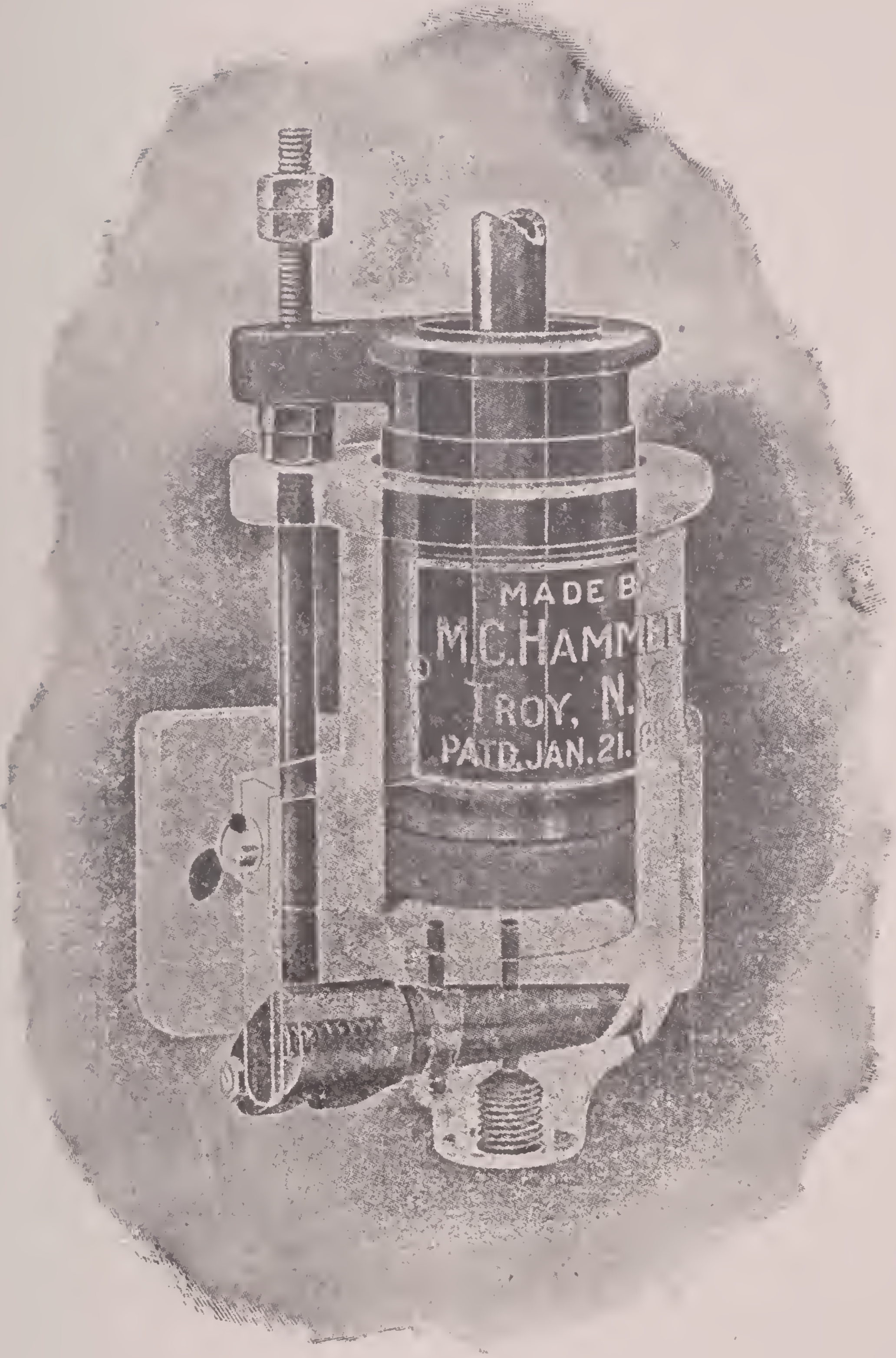


Fig. 53-a. Sansom Bell Ringer.

air in the cylinder almost to lifting point before admission.

Easily regulated to ring at any speed simply by control of air supplied.

OIL AS FUEL FOR LOCOMOTIVES.

The proper handling of fuel oil on a locomotive requires a greater degree of skill than is generally supposed to be the case, and the fact that a man may be an expert in the handling of coal does not go to show that he will succeed as an oil fireman.

There are a great many things that may happen to an oil-burner which will affect the steaming qualities, so that it is necessary to see that everything is in proper condition before starting.

Nothing will cause an engine to fail in steam any quicker than when the flue sheet and flues get covered with soot. This soot is the result of forced firing, or, in other words, allowing more oil to flow into the burner than is necessary, or that will be properly consumed with the amount of work the engine may be doing. In order to remove this soot from the flues, sand is used. This is introduced into the firebox by means of a funnel through a small hole made in the door for that purpose, and the funnel should be held so that the sand will be carried over, instead of under, the arch. The amount of sand that should be used all depends on the amount of soot that is on the flues, and sand should be used until all black smoke disappears.

The proper time to sand an engine is after leaving the roundhouse, when on the way to the train, as the flues generally get badly covered with soot resulting from firing up, and this should be all removed as soon as possible, but on account of the fact that a strong exhaust is necessary to properly clean out the flues, by carrying the sand over the arch and through the flues, it is generally advisable to wait until starting out with train, for, if the exhaust is not heavy or strong enough, the sand will do more harm than good, by dropping down on the bricks in floor of firebox and in front of burner, thereby interfering with the free passage of oil from burner to front of firebox. It should be seen to before starting that the firebox in front of the burner is free from any bricks, and that the floor of firebox is as smooth as possible, for when the bricks get rough they have a tendency to drag the fire, and the result is that the fire must be forced and black smoke follows.

To obtain thorough combustion in the firebox, a correct combination of steam and oil must be had, and this is obtained by admitting steam in the burner so that it will thoroughly mix or atomize the oil and spray it into the firebox. To enable the oil to flow freely from the tank to the burner, it must be heated. This is done by means of connecting a pipe so that steam will be led into the tank from the boiler. The connection between the engine and tank is generally made by means of a hose. In some types of heaters the pipe forms a coil inside of the tank, and there is a drain cock underneath which allows the water resulting from the condensation of the steam to pass off. This method, however, has proved very unsatisfactory, as it requires too long a time to heat the oil and a great many delays have been occasioned by the failure of the oil to run fast enough to the burner to maintain the desired pressure of steam on engines equipped with this style of heater. The most successful method of heating the oil is by allowing steam from heater pipe to flow directly into the oil, thus heating it in a very short space of time. The oil should be heated as much as possible while standing still, and the tank heater-valve should then be opened up strong and left on until oil is hot, and then closed. In order that the oil may be heated just before it reaches the burner, a super-heater is used. This consists merely of a pipe about a foot long, but twice as large around as the oil feed pipe. An opening large enough to allow the oil feed pipe to pass through is left at each end, and a slight pressure of steam is sufficient to heat the oil is maintained therein. A drain-cock is also used to allow the water formed by the condensation of the steam to pass off.

The drumming or rumbling sometimes occurring is the result of opening the atomizer-valve too much, or by allowing too much oil to flow to burner while engine is working slowly. If too much water is allowed to accumulate in the ashpan from the injector's overflow. the exhaust will draw it up into the firebox and the fire will be extinguished. A good plan is to make a few small holes in the bottom of the pan so that any surplus water will pass out. A pipe is connected from the super-heater to the oil feed pipe so that in case the burner should become choked up from one cause or another, by opening this valve, closing tank-valve, and opening the firing valve, steam will pass from the super-heater to oil feed pipe and thence to burner, and will blow out any obstruction that may be therein.

Sometimes the oil feed pipe becomes choked up, and by opening the tank-valve and closing the firing-valve the steam from super-heater flows back through feed pipe and blows any obstruction that may be in it back in the tank. It must be seen to that this blow-back valve, as it is called, is closed properly after having blown out the burner or the feed hose, for, should it be left open, it would interfere with the flow of oil to the burner and the fire will burn in a series of explosions.

Should the tank heater hose burst, so that oil in tank could not be heated in the proper manner, after closing the dampers and putting the fire out at the first stopping place, the oil may be heated in the following manner: Close firing-valve, open tank-valve if it is not already open, and by opening the blow-back valve the oil will be heated sufficiently.

Oil-burning locomotives are supposed to consume their own smoke, and if conditions are as they should be, they will. The conditions which give a smokeless oil-burning locomotive are so nicely balanced, however, that a very small margin is left to keep them in that condition.

It seems to be essential to first place the burner as low as possible, then tip it slightly up at the point, so that it flows or rolls in a natural course. If the point is tipped down, the tendency under light working is to strike the forward wall, then down according to the law of deflection, it must strike the front wall, then floor, and cut the path of the ingoing oil, which produces smoke and poor combustion.

It seems to be nearly as essential to admit the air over as large a surface as in burning coal, so that it may not deflect the flame and cool it at one point. If the construction is right, the handling and maintenance are just as important, and if properly handled there should be no smoke. But when there is absolutely no smoke, we are on the danger line in another direction, where the dropping of the lever or slipping of the engine will snuff out the fire, draw in cold air, and cause the flues to leak. In pulling out and getting under way, it is believed to be better practice to have a color of smoke than absolutely smokeless, to insure against this possibility, as many failures can be attributed to this cause.

A radical change from the ordinary methods of burning oil in locomotives has been inaugurated on the Southern Pacific Railway bv Mr. T. W. Heintzleman, Supt. of Motive Power, and Mr. J. G. Camp, General Foreman, at Sacramento, Cal.

It has been the usual practice to introduce the oil at the back end of the firebox, projecting the flame towards the front, and generally under a firebrick arch extending backward from the tube sheet, but Mr. Heintzleman and Mr. Camp reverse this method and introduce the oil through a burner placed in the front end of the firebox, projecting the fuel backward against a vertical fire brick wall built at the rear of the firebox, and below the fire door.

The usual fire brick arch is dispensed with altogether.

At the back end of the firebox an opening through the plate floor, that takes the place of the ash pan, admits air vertically upward against the flame immediately in front of the fire brick wall.

In some cases the atomizer passes through a hollow stay bolt in the front water leg.

There is no obstruction in the firebox, and the air coming direct upon the flame from beneath, deflects it in an upward direction, where it turns to travel forward towards the tubes. This gives a long flame-way for the fuel, and subjects a larger portion of the surface of the firebox to a direct heat, and prevents the concentration of the heat in certain portions of the box, which is liable to occur in connection with the usual method.

It is said that in the saving in the cost of the fire brick arches alone the saving due to this method is enormous, and to this must be added a very material improvement in the matter of injury to the firebox sheets, which is a serious difficulty in large locomotives where the fire with fuel oil is greatly forced.

COMBUSTION.

One of the duties that a fireman owes to himself, as well as to his employers, is that he utilizes his spare moments in the study of the theory of combustion, the composition of coal, the nature of heat, and various other problems connected with the generation of steam. He will be called upon to undergo an examination as to his knowledge of these questions at some stage of his apprenticeship, and the more intelligence he displays and the more thorough his answers, the faster will be his promotion. Therefore the author considers it fitting and proper that a space be given over at this point for the discussion of these important subjects.

One of the main factors in the combustion of coal is the proper supply of air. Air is composed of two gases, oxygen and nitrogen, in the proportion, by volume, of 21 per cent of oxygen and 79 per cent of nitrogen, or by weight, 23 per cent of oxygen and 77 per cent of nitrogen.

The composition of pure dry air is as follows:

By volume, 20.91 parts O. and 79.09 parts N.

By weight, 23.15 parts O. and 76.85 parts N.

Air is a mixture and not a chemical combination of these two elements. The principal constituent of coal and most other fuels, whether solid, liquid or gaseous, is carbon. Hydrogen is a light combustible gas and, combined either with carbon or with carbon and oxygen, in various proportions, is also a valuable constituent of fuels, notably of bituminous coal. The heating value of one pound of pure carbon is rated at 14,500 heat units, while one pound of hydrogen gas contains 62,000 heat units.

Analysis of coal shows that it contains moisture, fixed carbon, volatile matter, ash and sulphur in various proportions according to the quality of the coal. The following table will show the composition of the principal bituminous coals in use in this country for steam purposes. Two samples are selected from each of the great coal producing states, with the exception of Illinois, from which four were taken.

TABLE I

State	Kind of Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Pennsylvania	Youghiogheny	1.03	36.49	59.05	2.61	0.81
"	Connellsville	1.26	30.10	59.61	8.23	0.78
West Virginia	Quinimont	0.76	18.65	79.26	1.11	0.23
"	Fire Creek	0.61	22.34	75.02	1.47	0.56
E. Kentucky	Peach Orchard	4.60	35.70	53.28	6.42	1.08
"	Pike County	1.80	26.80	67.60	3.80	0.97
Alabama	Cahaba	1.66	33.28	63.04	2.02	0.53
"	Pratt Co.'s	1.47	32.29	59.50	6.73	1.22
Ohio	Hocking Valley	6.59	35.77	49.64	8.00	1.59
"	Muskingum "	3.47	37.88	53.30	5.35	2.24
Indiana	Block	8.50	31.00	57.50	3.00	
"	"	2.50	44.75	51.25	1.50	
W. Kentucky	Nolin River	4.70	33.24	54.94	11.70	2.54
"	Ohio County	3.70	30.70	45.00	3.16	1.24
Illinois	Big Muddy	6.40	30.60	54.60	8.30	1.50
"	Wilmington	15.50	32.80	39.90	11.80	
"	" screenings	14.00	28.00	34.20	23.80	
"	Duquoin	8.90	23.50	60.60	7.00	

The process of combustion consists in the union of the carbon and hydrogen of the fuel with the oxygen of the air. Each atom of carbon combines with two atoms of oxygen, and the energetic vibration set up by their combination is heat. Bituminous coal contains a large percentage of volatile matter which is released and flashes into flame when the coal is thrown into the furnace, and unless air is supplied in large amounts at this stage of the combustion there will be an excess of smoke and consequent loss of carbon. On the other hand, there is a loss in admitting too much air, because the surplus is heated to the temperature of the furnace without aiding the combustion and will carry off to the stack just as many heat units as were required to raise it from the temperature at which it entered the fire-box to that at which it leaves the flues. Some kinds of coal need more air for their combustion than do others, and good judgment and close observation are needed on the part of the fireman to properly regulate the supply.

The quantity of air required for the combustion of one pound of coal is, by volume, about 150 cu. ft.; by weight, about 12 lbs.

The temperature of the fire-box is usually about 2500°, in some cases reaching as high as 3000°. The temperature of the escaping gases should not be much above nor below 400° F. for bituminous coal.

In order to attain the highest economy in the burning of coal in boiler furnaces two factors are indispensable, viz., a constant high furnace temperature and quick combustion, and these factors can only be secured by supplying the fresh coal constantly just as fast as it is burned, and also by preventing as much as possible the admission of cold air at the furnace. The nitrogen in the atmosphere does not promote combustion, but it enters the fire-box along with the oxygen, and the heat required to raise its temperature to that of the other gases is practically wasted, and as has already been explained, if a surplus of cold air is allowed to pass into the fire-box the waste of heat becomes still greater.

Heat. All matter, whether solid, liquid, or gaseous, consists of molecules or atoms, which are in a state of continual vibration, and the result of this vibration is heat. The intensity of the heat evolved depends upon the degree of agitation to which the molecules are subject. Until as late as the beginning of the nineteenth century two rival theories in regard to the nature of heat had been advocated by scientists. The older of these theories was that heat was a material substance, a subtle elastic fluid termed caloric, and that this fluid penetrated matter as water penetrates a sponge. But this theory was shown to be false by the wonderful researches and experiments of Count Rumford at Munich, Bavaria, in 1798.

By means of the friction between two heavy metallic bodies placed in a wooden trough filled with water, one of the pieces of metal being rotated by machinery driven by horses, Count Rumford succeeded in raising the temperature of the water in two and one-half hours from its original temperature of 60° to 212° F., the boiling point, thus demonstrating that heat is not a material substance, but that it is due to vibration or motion, an internal commotion among the molecules of matter. This theory, known as the Kinetic theory of heat, has since been generally accepted, although it was nearly fifty years after Rumford advocated it in a paper read before the Royal Society of Great Britain in 1798, before scientists generally became converted to this idea of the nature of heat, and the science of Thermo Dynamics was placed on a firm basis.

During the period from 1840 to 1849 Dr. Joule made a series of experiments which not only confirmed the truth of Count Rumford's theory that heat was not a material substance but a form of energy which may be applied to or taken away from bodies, but Joule's experiments also established a method of estimating in mechanical units or foot pounds the amount of that energy. This latter was a most important discovery, because by means of it the exact relation between heat and work can be accurately measured.

The first law of thermo dynamics is this: Heat and mechanical energy or work are mutually convertible. That is, a certain amount of work will produce a certain amount of heat, and the heat thus produced is capable of producing by its disappearance a fixed amount of *mechanical* energy if rightly applied. The mechanical energy in the form of heat which, through the medium of the steam engine, has revolutionized the world, was first stored up by the sun's heat millions of years ago in the coal, which in turn, by combustion, is made to release it for purposes of mechanical work.

The general principles of Dr. Joule's device for measuring the amount of work in heat are illustrated in Fig. 54. It consisted of a small copper cylinder containing a known quantity of water at a known temperature. Inside the cylinder and extending through the top was a vertical shaft to which were fixed paddles for stirring the water. Stationary vanes were also placed inside the cylinder. Motion was imparted to the shaft through the medium of a cord or small rope coiled around a drum near the top of the shaft and running over a grooved pulley or sheave. To the free end of the cord a known weight was attached. This weight was allowed to fall through a certain distance, and in falling it turned the shaft with its paddles, which in turn agitated the water, thus producing a certain amount of heat. To illustrate, suppose the weight to be 77.8 lbs., and that by means of the crank at the top end of the shaft it has been raised to the zero mark at the top of the scale. (See Fig. 54.)

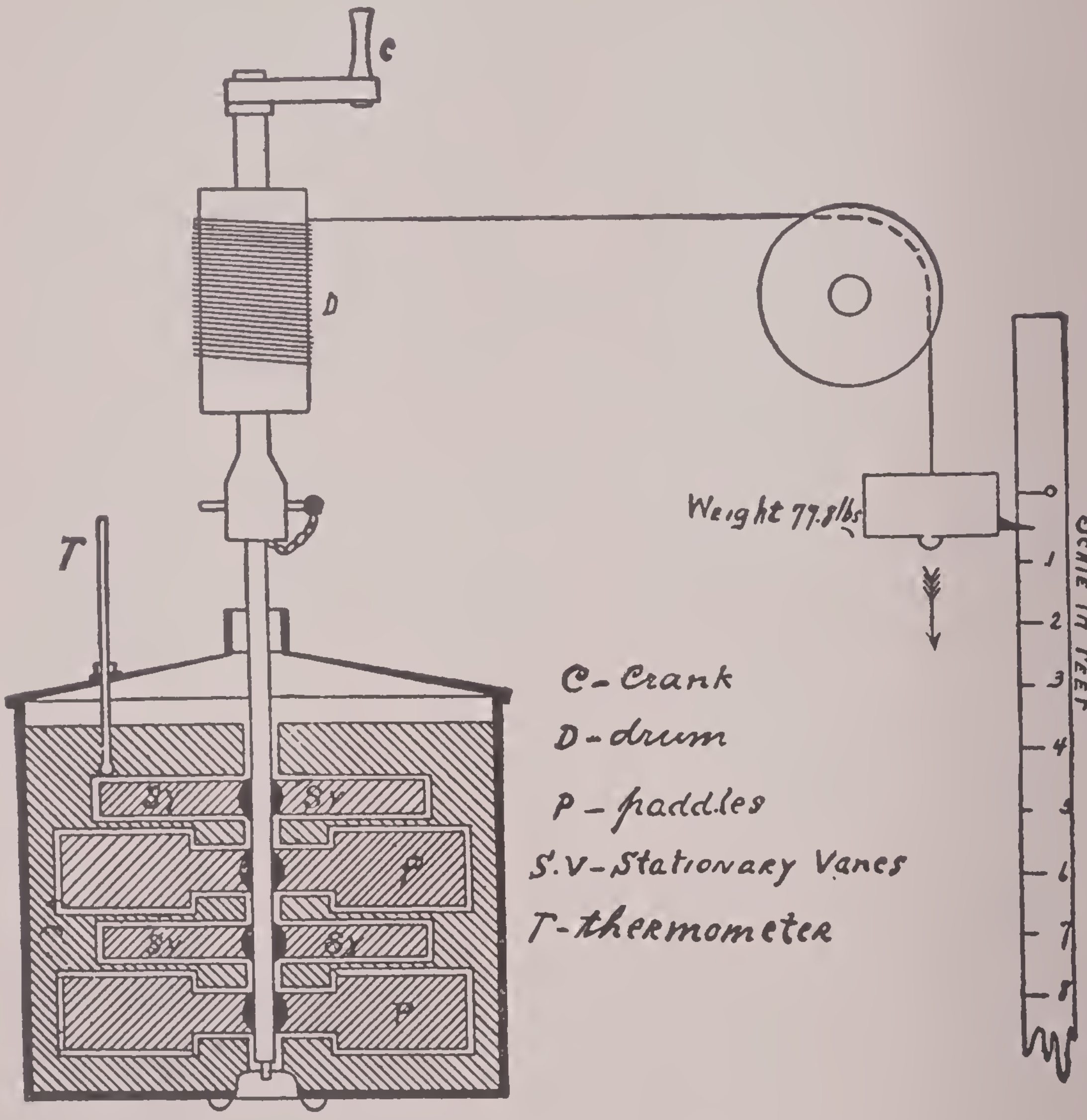


Fig. 54.

One pound of water at 39.1° F. is poured into the copper cylinder, which is then closed and the weight released. At the moment the weight passes the 10 ft. mark on the scale the thermometer attached to the cylinder will indicate that the temperature of the water has been raised one degree. Then multiplying the number of pounds in the weight by the distance in feet through which it fell will give the number of foot pounds of work done. Thus, 77.8 lbs. × 10 ft. = 778 foot pounds.

The heat unit or British thermal unit (B. T. U.) is the quantity of heat required to raise the temperature of one pound of water one degree, or from 39° to 40° F., and the amount of mechanical work required to produce a unit of heat is 778 foot pounds. Therefore the mechanical equivalent of heat is the energy required to raise 778 lbs. one foot high, or 77.8 lbs. 10 ft. high, or 1 lb. 778 feet high. Or again, suppose a one-pound weight falls through a space of 778 ft. or a weight of 778 lbs. falls one foot, enough mechanical energy would thus be developed to raise a pound of water one degree in temperature, provided all the energy so developed could be utilized in churning or stirring the water, as in Joule's machine. Hence the mechanical equivalent of heat is 778 foot pounds.

Specific Heat. The specific heat of any substance is the ratio of the quantity of heat required to raise a given weight of that substance one degree in temperature to the quantity of heat required to raise an equal weight of water one degree in temperature when the water is at its maximum density, 39.1° F. To illustrate, take the specific heat of lead, for instance, which is .031, while the specific heat of water is 1. That means that it would require 31 times as much heat to raise one pound of water one degree in temperature as it would to raise the temperature of a pound of lead one degree.

The following table gives the specific heat of different substances in which engineers are most generally interested.

TABLE 2

Water at 39.1° F.	1.000
Ice at 32° F.	.504
Steam at 212° F.	.480
Mercury	.033
Cast iron	.130
Wrought iron	.113
Soft steel	.116
Copper	.095
Lead	.031
Coal	.240
Air	.238
Hydrogen	3.404
Oxygen	.218
Nitrogen	.244

SENSIBLE HEAT AND LATENT HEAT. The plainest and most simple definition of these two terms is that given by Sir Wm. Thomson. He says: "Heat given to a body and warming it is sensible heat. Heat given to a body and not warming it is latent heat." Sensible heat in a substance is the heat that can be measured in degrees of a thermometer, while latent heat is the heat in any substance that is not shown by the thermometer.

To illustrate this more fully, a brief reference to some experiments made by Professor Black in 1762 will no doubt make the matter plain. It will be remembered that at that early date comparatively little was known of the true nature of heat; hence Professor Black's investigations and discoveries along this line appear all the more wonderful. He procured equal weights of ice at 32° F. and water at the same temperature, that is, just at the freezing point, and placing them in separate glass vessels, suspended the vessels in a room in which the uniform temperature was 47° F. He noticed that in one-half hour the water had increased 7° F. in temperature, but that twenty half hours elapsed before all of the ice was melted. Therefore he reasoned that twenty times more heat had entered the ice than had entered the water, because at the end of the twenty half hours, when the ice was all melted, the water in both vessels was of the same temperature. The water, having absorbed 7° of heat during the first half hour, must have continued to absorb heat at the same rate during the whole of the twenty half hours, although the thermometer did not indicate it. From this he calculated that 7° × 20 = 140° of heat had become latent or hidden in the water.

In another experiment Professor Black placed a lump of melting ice, which he estimated to be at a temperature of 33° F. on the surface, in a vessel containing the same weight of water at 176° F., and he observed that when the whole of the ice had been melted the temperature of the water was 33° F., thus proving that 143° of heat (176° — 33°) had been absorbed in melting the ice and was at that moment latent in the water. By these two experiments Professor Black established the theory of the latent heat of water, and his estimate was very near the truth, because the results obtained since that time by the greatest experimenters show that the latent heat of water is 142 heat units, or B. T. U.

Black's experiment for ascertaining the latent heat in steam at atmospheric pressure was made in the following simple manner: He placed a flat, open tin dish on a hot plate over a fire and into the dish he put a small quantity of water at 50° F. In four minutes the water began to boil, and in twenty minutes more it had all evaporated. In the first four minutes the temperature had increased $212° - 50° = 162°$, and the temperature remained at 212° throughout the twenty minutes that it required to evaporate all the water, despite the fact that the water had been receiving heat during this period at the same rate as during the first four minutes. He therefore reasoned that in the twenty minutes the water had absorbed five times as much heat as it had in the four minutes, or $162° \times 5 = 810°$, without any sensible rise in temperature. Therefore the 810° became latent in the steam. Owing to the crude nature of the experiment Professor Black's estimate of the number of degrees of latent heat in steam was incorrect, as it has been proven by many famous experimenters since then that the latent heat of steam at atmospheric pressure is 965.7 B. T. U.

It will thus be perceived that what is meant by the term latent heat is that quantity of heat which becomes hidden or latent when the state of a body is changed from a solid to a liquid, as in the case of melting ice, or from a liquid to a gaseous state, as with water evaporated into steam. But the heat so disappearing has not been lost; on the contrary it has, while becoming latent, been doing an immense amount of work, as can easily be ascertained by means of a few simple figures. It has been seen that a heat unit is the quantity of heat required to raise one pound of water one degree in temperature and also that the mechanical equivalent of heat, or, in other words, the mechanical energy stored in one heat unit, is equal to 778 foot pounds of work.

A horse power equals 33,000 ft. lbs. of energy in one minute of time, and a heat unit = 778 ÷ 33,000 = .0236, or about 1-43 of a horse power. The work done by the heat which becomes latent in converting one pound of ice at 32° F. into water at the same temperature = 142 heat units × 778 ft. lbs. = 110,476 ft. lbs., which divided by 33,000 equals 3.34 horse power. Again, by the evaporation of one pound of water from 32° F. into steam at atmospheric pressure, 965.7 units of heat become latent in the steam and the work done = 965.7 × 778 = 751,314 ft. lbs. = 22.7 horse power. It will thus be seen what tremendous energy lies stored in one pound of coal, which contains from 12,000 to 14,500 heat units, provided all the heat could be utilized in an engine.

TOTAL HEAT OF EVAPORATION. In order to raise the temperature of one pound of water from the freezing point, 32° F., to the boiling point, 212° F., there must be added to the temperature of the water 212° — 32° = 180°. This represents the sensible heat. Then to make the water boil at atmospheric pressure, or, in other words, to evaporate it, there must still be added 965.7 B. T. U., thus 180 + 965.7 = 1,145.7, or in round numbers 1,146 heat units. This represents what is termed the total heat of evaporation at atmospheric pressure and is the sum of the sensible and latent heat in steam at that pressure. But if a thermometer were held in steam evaporating into the open air, as for instance, in front of the spout of a tea kettle, it would indicate but 212° F.

When steam is generated at a higher pressure than 212°, the sensible heat increases and the latent heat decreases slowly, while at the same time the total heat of evaporation slowly increases as the pressure increases, but not in the same ratio. As, for instance, the total heat in steam at atmospheric pressure is 1,146 B. T. U., while the total heat in steam at 100 lbs. gauge pressure is 1,185 B. T. U., and the sensible temperature of steam at atmospheric pressure is 212°, while at 100 lbs. gauge pressure the temperature is 338 and the latent heat is 876 B. T. U. See Table 4.

WATER. The elements that enter into the composition of pure water are the two gases, hydrogen and oxygen, in the following proportions:

By volume, hydrogen 2, oxygen 1.
By weight, " 11.1, " 88.9.

Perfectly pure water is not attainable, neither is it desirable nor necessary to the welfare of the human race, because the presence of certain proportions of air and ammonia add greatly to its value as an agent for manufacturing purposes and for generating steam. The nearest approach to pure water is rain water, but even this contains 2.5 volumes of air to each 100 volumes of water. Pure distilled water, such for instance as the return water from steam heating systems, is not desirable for use alone in a boiler, as it will cause corrosion and pitting of the sheets, but if it is mixed with other water before going into the boiler its use is highly beneficial, as it will prevent to a certain degree the formation of scale and incrustation. Nearly all water used for the generation of steam in boilers contains more or less scale-forming matter, such as the carbonates of lime and magnesia, the sulphates of lime and magnesia, oxide of iron, silica and organic matter, which latter tends to cause foaming in boilers.

The carbonates of lime and magnesia are the chief causes of incrustation. The sulphate of lime forms a hard crystalline scale which is extremely difficult to remove when once formed on the sheets and tubes of boilers. Of late years the intelligent application of chemistry to the analyzing of feed waters has been of great benefit to engineers and steam users, in that it has enabled them to properly treat the water with solvents either before it is pumped into the boiler or by the introduction into the boiler of certain scale preventing compounds especially for treating the particular kind of water used. Where it is necessary to treat water in this manner, great care and watchfulness should be exercised by the engineer in the selection and use of a boiler compound.

From 10 to 40 grains of mineral matter per gallon are held in solution by the waters of the different rivers, streams and lakes; well and mine water contain more.

Water contracts and becomes denser in cooling until it reaches a temperature of 39.1° F., its point of greatest density. Below this temperature it expands, and at 32° F. it becomes solid or freezes, and in the act of freezing expands considerably, as every engineer who has to deal with frozen water pipes can testify.

Water is 815 times heavier than atmospheric air. The weight of a cubic foot of water at 39.1° is approximately 62.5 lbs., although authorities differ on this matter, some of them placing it at 62.379 lbs., and others at 62.425 lbs. per cubic foot. As its temperature increases its weight per cubic foot decreases, until at 212° F. one cubic foot weighs 59.76 lbs.

The table which follows is compiled from various sources and gives the weight of a cubic foot of water at different temperatures.

TABLE 3

Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot
32° F.	62.42 lbs.	132° F.	61.52 lbs.	230° F.	59.37 lbs.
42°	62.42	142°	61.34	240°	59.10
52°	62.40	152°	61.14	250°	58.85
62°	62.36	162°	60.94	260°	58.52
72°	62.30	172°	60.73	270°	58.21
82°	62.21	182°	60.50	300°	57.26
92°	62.11	192°	60.27	330°	56.24
102°	62.00	202°	60.02	360°	55.16
112°	61.86	212°	59.76	390°	54.03
122°	61.70	220°	59.64	420°	52.86

The boiling point of water varies according to the pressure to which it is subject. In the open air at sea level the boiling point is 212° F. When confined in a boiler under steam pressure the boiling point of water depends upon the pressure and temperature of the steam, as, for instance, at 100 lbs. gauge pressure the temperature of the steam is 338° F., to which temperature the water must be raised before its molecules will separate and be converted into steam. In the absence of any pressure, as in a perfect vacuum, water boils at 32° F. temperature. In a vacuum of 28 in., corresponding to an absolute pressure of .943 lbs., water will boil at 100°, and in a vacuum of 26 in., at which the absolute pressure is 2 lbs., the boiling point of water is 127° F. On the tops of high mountains in a rarefied atmosphere water will boil at a much lower temperature than at sea level; for instance, at an altitude of 15,000 ft. above sea level water boils at 184° F.

STEAM. Having discussed to some extent the physical properties of water, it is now in order to devote some time to the study of the nature of steam, which is simply water in its gaseous form, made so by the application of heat.

As has been stated in another portion of this book, matter consists of molecules or atoms inconceivably small in size, yet each having an individuality, and in the case of solids or liquids, each having a mutual cohesion or attraction for the other, and all being in a state of continual vibration more or less violent according to the temperature of the body.

The law of gravitation, which holds the universe together, also exerts its wonderful influence on these atoms and causes them to hold together with more or less tenacity according to the nature of the substance. Thus it is much more difficult to chip off pieces of iron or granite than it is of wood. But in the case of water and other liquids the atoms, while they adhere to each other to a certain extent, still are not so hard to separate; in fact, they are to some extent repulsive to each other, and unless confined within certain bounds the atoms will gradually scatter and spread out, and finally either be evaporated or sink out of sight in the earth's surface. Heat applied to any substance tends to accelerate the vibrations of the molecules, and if enough heat is applied it will reduce the hardest substances to a liquid or gaseous state.

The process of the generation of steam from water is simply an increase of the natural vibrations of the molecules of the water, caused by the application of heat, until they lose all attraction for each other and become instead entirely repulsive, and unless confined will fly off into space. But, being confined, they continually strike against the sides of the containing vessel, thus causing the pressure which steam or any other gas exerts when under confinement.

Of course steam, like other gases, when under pressure is invisible, but the laws governing its action are well known. These laws, especially those relating to the expansion of steam, will be more fully discussed in the chapter on the Indicator. The temperature of steam in contact with the water from which it is generated, as for instance in the ordinary steam boiler, depends upon the pressure under which it is generated. Thus at atmospheric pressure its temperature is 212° F. If the vessel is closed and the pressure increased the temperature of the steam and also that of the water rises.

Saturated Steam. When steam is taken directly from the boiler to the engine without being superheated, it is termed saturated steam. This does not necessarily imply that it is wet and mixed with spray and moisture.

Superheated Steam. When steam is conducted into or through a vessel or coils of pipe separate from the boiler in which it was generated and is there heated to a higher temperature than that due to its pressure, it is said to be superheated.

Dry Steam. When steam contains no moisture it is said to be dry. Dry steam may be either saturated or superheated.

Wet Steam. When steam contains mist or spray intermingled, it is termed wet steam, although it may have the same temperature as dry saturated steam of the same pressure.

During the further consideration of steam in this book, saturated steam will be mainly under discussion, for the reason that this is the normal condition of steam as used most generally in steam engines.

Total Heat of Steam. The total heat in steam includes the heat required to raise the temperature of the water from 32° F. to the temperature of the steam plus the heat required to evaporate the water at that temperature. This latter heat becomes latent in the steam, and is therefore called the latent heat of steam.

The work done by the heat acting within the mass of water and causing the molecules to rise to the surface is termed by scientists internal work, and the work done in compressing the steam already formed in the boiler or in pushing it against the superincumbent atmosphere, if the vessel be open, is termed external work. There are, therefore, in reality three elements to be taken into consideration in estimating the total heat of steam, but as the heat expended in doing external work is done within the mass itself, it may, for practical purposes, be included in the general term latent heat of steam.

Density of Steam. The expression density of steam means the actual weight in pounds or fractions of a pound avoirdupois of a given volume of steam, as one cubic foot. This is a very important point for young engineers especially to remember, so as not to get the two terms, pounds pressure and pounds weight, mixed, as some are prone to do.

Volume of Steam. By this term is meant the volume as expressed by the number of cubic feet in one pound weight of steam.

Relative Volume of Steam. This expression has reference to the number of volumes of steam produced from one volume of water. Thus the steam produced by the evaporation of one cubic foot of water from 39° F. into steam at atmospheric pressure will occupy a space of 1646 cu. ft., but, as the steam is compressed and the pressure allowed to rise, the relative volume of the steam becomes smaller, as, for instance, at 100 lbs. gauge pressure the steam produced from one cubic foot of water will occupy but 237.6 cu. ft., and if the same steam was compressed to 1,000 lbs. absolute or 985.3 lbs. gauge pressure it would then occupy only 30 cu. ft.

TABLE 4

PROPERTIES OF SATURATED STEAM

Vacuum Inches of Mercury	Absolute Pressure Lbs. per Sq. Inch	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
29 74	.089	32.	0.	1091 7	1091.7	208,080	3333.3	.0003
29.67	.122	40.	8.	1094.1	1086.1	154,330	2472.2	.0004
29.56	.176	50	18.	1097.2	1079.2	107,630	1724.1	.0006
29.40	.254	60.	28.01	1100.2	1072.2	76,370	1223.4	.0008
29.19	.359	70.	38.02	1103.3	1065.3	54,660	875.61	.0011
28.90	.502	80.	48.04	1106.3	1058.3	39,690	635.80	.0016
28.51	.692	90.	58.06	1109.4	1051.3	29,290	469.20	.0021
28.00	.943	100.	68.08	1112.4	1044.4	21,830	349.70	.0028
27.88	1.	102.1	70.09	1113.1	1043.0	20,623	334.23	.0030
25.85	2.	126.3	94.44	1120.5	1026.0	10,730	173.23	.0058
23.83	3.	141.6	109.9	1125.1	1015.3	7,325	118.00	.0085
21.78	4.	153.1	121.4	1128.6	1007.2	5,588	89.80	.0111
19.74	5.	162.3	130.7	1131.4	1000.7	4,530	72.50	.0137
17.70	6.	170.1	138.6	1133.8	995.2	3 816	61.10	.0163
15.67	7.	176.9	145.4	1135.9	990.5	3,302	53.00	.0189
13.63	8.	182.9	151.5	1137.7	986.2	2,912	46.60	.0214
11.60	9.	188.3	156.9	1139.4	982.4	2,607	41.82	.0239
9.56	10.	193.2	161.9	1140.9	979.0	2,361	37.80	.0264
7.52	11.	197.8	166.5	1142.3	975.8	2,159	34.61	.0289
5.49	12.	202.0	170.7	1143.5	972.8	1,990	31.90	.0314
3.45	13.	205.9	174.7	1144.7	970.0	1,846	29.60	.0338
1.41	14.	209.6	178.4	1145.9	967.4	1,721	27.50	.0363
0.00	14.7	212.0	180.9	1146.6	963.7	1,646	26.36	.0379

TABLE 4—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
0.3	15	213.3	181.9	1146.9	965.0	1,614	25.90	.0387
1.3	16	216.3	185.3	1147.9	962.7	1,519	24.33	.0411
2.3	17	219.4	188.4	1148.9	960.5	1,434	23.00	.0435
3.3	18	222.4	191.4	1149.8	958.3	1,359	21.80	.0459
4.3	19	225.2	194.3	1150.6	956.3	1,292	20.70	.0483
5.3	20	227.9	197.0	1151.5	954.4	1,231	19.72	.0507
6.3	21	230.5	199.7	1152.2	952.6	1,176	18.84	.0531
7.3	22	233.0	202.2	1153.0	950.8	1,126	18.03	.0555
8.3	23	235.4	204.7	1153.7	949.1	1,080	17.30	.0578
9.3	24	237.8	207.0	1154.5	947.4	1,038	16.62	.0602
10.3	25	240.0	209.3	1155.1	945.8	998	16.00	.0625
11.3	26	242.2	211.5	1155.8	944.3	962	15.42	.0649
12.3	27	244.3	213.7	1156.4	942.8	929	14.90	.0672
13.3	28	246.3	215.7	1157.1	941.3	898	14.40	.0696
14.3	29	248.3	217.8	1157.7	939.9	869	13.91	.0719
15.3	30	250.2	219.7	1158.3	938.9	841	13.50	.0742
16.3	31	252.1	221.6	1158.8	937.2	816	13.07	.0765
17.3	32	254.0	223.5	1159.4	935.9	792	12.68	.0788
18.3	33	255.7	225.3	1159.9	934.6	769	12.32	.0812
19.3	34	257.5	227.1	1160.5	933.4	748	12.00	.0835
20.3	35	259.2	228.8	1161.0	932.2	728	11.66	.0858
21.3	36	260.8	230.5	1161.5	931.0	709	11.36	.0880
22.3	37	262.5	232.1	1162.0	929.8	691	11.07	.0903
23.3	38	264.0	233.8	1162.5	928.7	674	10.80	.0926
24.3	39	265.6	235.4	1162.9	927.6	658	10.53	.0949
25.3	40	267.1	236.9	1163.4	926.5	642	10.28	.0972
26.3	41	268.6	238.5	1163.9	925.4	627	10.05	.0995
27.3	42	270.1	240.0	1164.3	924.4	613	9.83	.1018
28.3	43	271.5	241.4	1164.7	923.3	600	9.61	.1040
29.3	44	272.9	242.9	1165.2	922.3	587	9.41	.1063
30.3	45	274.3	244.3	1165.6	921.3	575	9.21	.1086
31.3	46	275.7	245.7	1166.0	920.4	563	9.02	.1108
32.3	47	277.0	247.0	1166.4	919.4	552	8.84	.1131
33.3	48	278.3	248.4	1166.8	918.5	541	8.67	.1153
34.3	49	279.6	249.7	1167.2	917.5	531	8.50	.1176
35.3	50	280.9	251.0	1167.6	916.6	520	8.34	.1198
36.3	51	282.1	252.2	1168.0	915.7	511	8.19	.1221
37.3	52	283.3	253.5	1168.4	914.9	502	8.04	.1243

TABLE 4—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
38.3	53	284.5	254.7	1168.7	914.0	492	7.90	.1266
39.3	54	285.7	256.0	1169.1	913.1	484	7.76	.1288
40.3	55	286.9	257.2	1169.4	912.3	476	7.63	.1311
41.3	56	288.1	258.3	1169.8	911.5	468	7.50	.1333
42.3	57	289.1	259.5	1170.1	910.6	460	7.38	.1355
43.3	58	290.3	260.7	1170.5	909.8	453	7.26	.1377
44.3	59	291.4	261.8	1170.8	909.0	446	7.14	.1400
45.3	60	292.5	262.9	1171.2	908.2	439	7.03	.1422
46.3	61	293.6	264.0	1171.5	907.5	432	6.92	.1444
47.3	62	294.7	265.1	1171.8	906.7	425	6.82	.1466
48.3	63	295.7	266.2	1172.1	905.9	419	6.72	.1488
49.3	64	296.8	267.2	1172.4	905.2	413	6.62	.1511
50.3	65	297.8	268.3	1172.8	904.5	407	6.53	.1533
51.3	66	298.8	269.3	1173.1	903.7	401	6.43	.1555
52.3	67	299.8	270.4	1173.4	903.0	395	6.34	.1577
53 3	68	300.8	271.4	1173.7	902.3	390	6.25	.1599
54.3	69	301.8	272.4	1174.0	901.6	384	6.17	.1621
55.3	70	302.7	273.4	1174.3	900.9	379	6.09	.1643
56.3	71	303.7	274.4	1174.6	900.2	374	6.01	.1665
57.3	72	304.6	275.3	1174.8	899.5	369	5.93	.1687
58.3	73	305.6	276.3	1175.1	898.9	365	5.85	.1709
59.3	74	306.5	277.2	1175.4	898.2	360	5.78	.1731
60.3	75	307.4	278.2	1175.7	897.5	356	5.71	.1753
61.3	76	308.3	279.1	1176.0	896.9	351	5.63	.1775
62.3	77	309.2	280.0	1176.2	896.2	347	5.57	.1797
63.3	78	310.1	280.9	1176.5	895.6	343	5.50	.1819
64.3	79	310.9	281.8	1176.8	895.0	339	5.43	.1840
65.3	80	311.8	282.7	1177.0	894.3	334	5.37	.1862
66.3	81	312.7	283.6	1177.3	893.7	331	5.31	.1884
67.3	82	313.5	284.5	1177.6	893.1	327	5.25	.1906
68.3	83	314.4	285.3	1177.8	892.5	323	5.18	.1928
69.3	84	315.2	286.2	1178.1	891.9	320	5.13	.1950
70.3	85	316.0	287.0	1178.3	891.3	316	5.07	.1971
71.3	86	316.8	287.9	1178.6	890.7	313	5.02	.1993
72.3	87	317.7	288.7	1178.8	890.1	309	4.96	.2015
73.3	88	318.5	289.5	1179.1	889.5	306	4.91	.2036
74.3	89	319.3	290.4	1179.3	888.9	303	4.86	.2058
75.3	90	320.0	291.2	1179.6	888.4	299	4.81	.2080

TABLE 4—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
76.3	91	320.8	292.0	1179.8	887.8	296	4.76	.2102
77.3	92	321.6	292.8	1180.0	887.2	293	4.71	.2123
78.3	93	322.4	293.6	1180.3	886.7	290	4.66	.2145
79.3	94	323.1	294.4	1180.5	886.1	287	4.62	.2166
80.3	95	323.9	295.1	1180.7	885.6	285	4.57	.2188
81.3	96	324.6	295.9	1181.0	885.0	282	4.53	.2210
82.3	97	325.4	296.7	1181.2	884.5	279	4.48	.2231
83.3	98	326.1	297.4	1181.4	884.0	276	4.44	.2253
84.3	99	326.8	298.2	1181.6	883.4	274	4.40	.2274
85.3	100	327.6	298.9	1181.8	882.9	271	4.36	.2296
86.3	101	328.3	299.7	1182.1	882.4	268	4.32	.2317
87.3	102	329.0	300.4	1182.3	881.9	266	4.28	.2339
88.3	103	329.7	301.1	1182.5	881.4	264	4.24	.2360
89.3	104	330.4	301.9	1182.7	880.8	261	4.20	.2382
90.3	105	331.1	302.6	1182.9	880.3	259	4.16	.2403
91.3	106	331.8	303.3	1183.1	879.8	257	4.12	.2425
92.3	107	332.5	304.0	1183.4	879.3	254	4.09	.2446
93.3	108	333.2	304.7	1183.6	878.8	252	4.05	.2467
94.3	109	333.9	305.4	1183.8	878.3	250	4.02	.2489
95.3	110	334.5	306.1	1184.0	877.9	248	3.98	.2510
96.3	111	335.2	306.8	1184.2	877.4	246	3.95	.2531
97.3	112	335.9	307.5	1184.4	876.9	244	3.92	.2553
98.3	113	336.5	308.2	1184.6	876.4	242	3.88	.2574
99.3	114	337.2	308.8	1184.8	875.9	240	3.85	.2596
100.3	115	337.8	309.5	1185.0	875.5	238	3.82	.2617
101.3	116	338.5	310.2	1185.2	875.0	236	3.79	.2638
102.3	117	339.1	310.8	1185.4	874.5	234	3.76	.2660
103.3	118	339.7	311.5	1185.6	874.1	232	3.73	.2681
104.3	119	340.4	312.1	1185.8	873.6	230	3.70	.2703
105.3	120	341.0	312.8	1185.9	873.2	228	3.67	.2764
106.3	121	341.6	313.4	1186.1	872.7	227	3.64	.2745
107.3	122	342.2	314.1	1186.3	872.3	225	3.62	.2766
108.3	123	342.9	314.7	1186.5	871.8	223	3.59	.2788
109.3	124	343.5	315.3	1186.7	871.4	221	3.56	.2809
110.3	125	344.1	316.0	1186.9	870.9	220	3.53	.2830
111.3	126	344.7	316.6	1187.1	870.5	218	3.51	2851
112.3	127	345.3	317.2	1187.3	870.0	216	3.48	.2872
113.3	128	345.9	317.8	1187.4	869.6	215	3.46	.2894

TABLE 4—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
114.3	129	346.5	318.4	1187.6	869.2	213	3.43	.2915
115.3	130	347.1	319.1	1187.8	868.7	212	3.41	.2936
116.3	131	347.6	319.7	1188.0	868.3	210	3.38	.2957
117.3	132	348.2	320.3	1188.2	867.9	209	3.36	.2978
118.3	133	348.8	320.8	1188.3	867.5	207	3.33	.3000
119.3	134	349.4	321.5	1188.5	867.0	206	3.31	.3021
120.3	135	350.0	322.1	1188.7	866.6	204	3.29	.3042
121.3	136	350.5	322.6	1188.9	866.2	203	3.27	.3063
122.3	137	351.1	323.2	1189.0	865.8	201	3.24	.3084
123.3	138	351.8	323.8	1189.2	865.4	200	3.22	.3105
124.3	139	352.2	324.4	1189.4	865.0	199	3.20	.3126
125.3	140	352.8	325.0	1189.5	864.6	197	3.18	.3147
126.3	141	353.3	325.5	1189.7	864.2	196	3.16	.3169
127.3	142	353.9	326.1	1189.9	863.8	195	3.14	.3190
128.3	143	354.4	326.7	1190.0	863.4	193	3.11	.3211
129.3	144	355.0	327.2	1190.2	863.0	192	3.09	.3232
130.3	145	355.5	327.8	1190.4	862.6	191	3.07	.3253
131.3	146	356.0	328.4	1190.5	862.2	190	3.05	.3274
133.3	148	357.1	329.5	1190.9	861.4	187	3.02	.3316
135.3	150	358.2	330.6	1191.2	860.6	185	2.98	.3358
140.3	155	360.7	333.2	1192.0	858.7	179	2.89	.3463
145.3	160	363.3	335.9	1192.7	856.9	174	2.80	.3567
150.3	165	365.7	338.4	1193.5	855.1	169	2.72	.3671
155.3	170	368.2	340.9	1194.2	853.3	164	2.65	.3775
160.3	175	370.5	343.4	1194.9	851.6	160	2.58	.3879
165.3	180	372.8	345.8	1195.7	849.9	156	2.51	.3983
170.3	185	375.1	348.1	1196.3	848.2	152	2.45	.4087
175.3	190	377.3	350.4	1197.0	846.6	148	2.39	.4191
180.3	195	379.5	352.7	1197.7	845.0	144	2.33	.4296
185.3	200	381.6	354.9	1198.3	843.4	141	2.27	.4400
190.3	205	383.7	357.1	1199.0	841.9	138	2.22	.4503
195.3	210	385.7	359.2	1199.6	840.4	135	2.17	.4605
200.3	215	387.7	361.3	1200.2	838.9	132	2.12	.4707
205.3	220	389.7	362.2	1200.8	838.6	129	2.06	.4852
245.3	260	404.4	377.4	1205.3	827.9	110	1.76	.5686
285.3	300	417.4	390.9	1209.2	818.3	96	1.53	.6515
485.3	500	467.4	443.5	1224.5	781.0	59	.94	1.062
685.3	700	504.1	482.4	1235.7	753.3	42	.68	1.470
985.3	1000	546.8	528.3	1248.7	720.3	30	.48	2.082

The condition of steam as regards its dryness may be approximately estimated by observing its appearance as it issues from a pet cock or other small opening into the atmosphere. Dry or nearly dry steam containing about 1 per cent of moisture will be transparent close to the orifice through which it issues, and even if it is of a grayish white color it may be estimated to contain not over 2 per cent of moisture.

Steam in its relation to the engine should be considered in the character of a vehicle for transferring the energy, created by the heat, from the boiler to the engine. For this reason all steam drums, headers and pipes should be thoroughly insulated, in order to prevent, as much as possible, the loss of heat or energy by radiation.

Table 4 gives the physical properties of steam, and is convenient for reference.

QUESTIONS

1. What is one of the most important of a fireman's duties?

2. What should the fireman attend to first of all when getting his engine ready to start out from the roundhouse?

3. What other details should be looked after at this time?

4. What condition should his fire be in before leaving a terminal?

5. What is the proper depth of fire to be carried?

6. Should the fireman read and understand the train orders?

7. How should the coal be supplied to the fire while running?

8. What is the best rule for the fireman to observe?

9. In what parts of the fire-box does the fire burn the heaviest generally speaking?

10. What system of firing gives good results?

11. What precautions should the fireman take regarding the lay of the road, the location of the grades, and the requirements of the engine as to steam?

12. How should the water be fed to the boiler?

13. If the boiler has a tendency to foam, what precautions must be observed?

14. If there is an overflow of water in the boiler, what effect does the blowing of the pop valve have?

15. What precautions should a fireman practice respecting admission of air to the fire-box?

16. How may he prevent the grates from being burned out?

17. Explain why the exhaust creates such a strong draft.

18. When should the blower be used?

19. Why is a larger grate area required for hard coal than for soft coal?

20. What conditions control the depth of a hard coal fire?

21. If a hard coal fire were allowed to become too thin, what would be the result?

22. What is the secret of success in firing hard coal?

23. How often should the grates be shaken when firing soft coal?

24. What effect does firing the coal in big lumps have?

25. What results follow from leaving the door open while firing two or three scoops of coal?

26. What is the proper way to fire?

27. Describe the route taken by the air in its passage through a locomotive when in operation.

28. Explain the action of the exhaust steam after leaving the cylinders.

29. Why does the exhaust create such a tremendous draft?

30. When there is less atmospheric pressure in the front end than there is outside assuming the front end to be air tight, what is the result?

31. Explain the action of the blower.

32. What conditions are requisite in order to obtain good combustion?

33. What is a diaphragm, or deflector plate and what are its functions?

34. What is the object in placing a netting in the front end?

35. How is the force or intensity of the draft regulated with the Master Mechanic's front end?

36. How may an even burning fire be obtained with this arrangement?

37. If the fire burns too fast near the flue sheet, what should be done?

38. If the fire burns too strongly near the door what is to be done?

39. How is the supply of air to the fire to be governed?

40. How is the draft affected if the exhaust jet does not fill the stack near the base?

41. How is the petticoat pipe generally located?

42. What will be the result of using a small nozzle?

43. What tendency does a bridge in the nozzle have?

44. What effect does raising or lowering the sleeve of the petticoat pipe have upon the draft?

45. Describe briefly the Wallace and Kellogg adjustable nozzle.

46. Give the nozzle areas for different positions of the reverse lever.

47. Mention the names of other draft regulating devices in use.

48. Describe in brief terms the front end known as the Master Mechanic's.

49. What precautions are to be observed regarding the opening under the diaphragm with this front end?

50. How may the draft through the back end of the fire-box be increased?

51. What is the object of the projecting wings at each end of the diaphragm?

52. What results should the most efficient diaphragm give?

53. What should be the angle of such a diaphragm?

54. What is the object of increasing the angle of the diaphragm?

55. What is the function of the perforated steel plate at the back side of the diaphragm?

56. What vacuum is obtained at various points inside the stack?

57. What are the pressures in the center of the exhaust jet, at various heights above the nozzle?

58. Does the point of cut-off that the engine is working at affect the efficiency of the jet?

59. Is there any advantage gained by contraction of the nozzle in order to increase the rate of combustion?

60. What is the most efficient form of exhaust nozzle?

61. What should be the distance of the nozzle from the choke of a 14″ x 52″ stack on a 58″ front end?

62. What should be the distance of the nozzle from the top of the smoke arch with a 14″ x 52″ stack?

63. What should be the distance of the nozzle from the top of the arch with a 16″ x 52″ straight stack?

64. What are the requirements of the stack as to taper, diameter, and height in order to obtain the highest efficiency?

65. How does the petticoat pipe or draft pipe add to the efficiency of the front end?

66. Should the jet come in contact with the pipe?

67. What was the position of the draft pipe relative to the top of the nozzle in tests showing the highest efficiency?

68. What were the dimensions of the petticoat pipe used in the tests?

69. What should be the area of netting?

70. What is the chief objection to the perforated steel plate?

71. What point is in its favor?

72. What can be said of the Smith Triple Expansion Exhaust pipe?

73. How large should the area for the admission of air through the ash pan be?

74. How many pounds of coal are burned per sq. ft. of grate area per hour?

75. How much air is required per pound of coal burned?

76. What should be the ratios of ash pan openings, relative to areas of flues, and to cylinder volumes?

77. In what three ways may the draft action be checked?

78. Speaking of the netting, what is meant by 2½″ mesh netting?

79. How is the force of the draft measured?

80. When is a locomotive said to be a good steamer?

81. What is the proper method to pursue when making changes in the drafting arrangement?

82. About how many square feet of grate surface are needed to burn one ton of soft coal per hour?

83. Describe a water grate.

84. Describe the working of the Brewer Fire Door Opener.

85. Describe the action of the Bates fire box door.

86. What can be said concerning the Mechanical Stoker?

87. Mention some of the advantages said to be gained by its use.

88. What are the dimensions of the Victor Locomotive Stoker?

89. Describe briefly its action.

90. What are the directions for firemen operating this stoker?

91. What must be done in case of accident to the stoker while out on the road?

92. Describe the operation of the Hayden Mechanical Stoker.

93. Describe the action of the Ryan-Johnson improvement attached to tenders.

94. What are some of the advantages said to be gained by the use of the McCanna Force Feed Lubricator?

95. What four rules are to be observed in the operation of the Nathan New Bull's-Eye Lubricator?

96. What are the direction for operating the Nathan Triple Sight Feed Lubricator?

97. What are the rules for operating the Detroit No. 21 Triple Feed Lubricator?

98. What is liable to cause a small drop of oil in a sight feed lubricator?

99. How can this be remedied?

100. What is meant by a lubricator being air-bound?

101. How may this be overcome?

102. What are the principles governing the action of a sight feed lubricator?

103. What can be said regarding the use of oil as a fuel for locomotives?

104. What will cause accumulations of soot on the flue sheet and flues?

105. How is the soot removed?

106. When is the proper time to do this?

107. What other precautions should be taken regarding the fire-box of an oil burner?

108. What is necessary in order to obtain thorough combustion of the oil?

109. What must be done with the oil to cause it to flow freely from the tank to the burner?

110. How may this be accomplished most successfully?

111. Describe a superheater in connection with the oil burner.

112. What causes the drumming or rumbling noise sometimes produced on an oil burner?

113. What is the result if too much water from the injector's overflow is allowed to accumulate in the ash pit?

114. In case the oil burner should become choked up, how may it be cleaned?

115. If the oil feed pipe becomes choked, how may it be cleaned?

116. If the tank heater hose should burst, how may the oil in the tank be heated?

117. What conditions are necessary in order to prevent making smoke on an oil-burning locomotive?

118. At what part of the fire-box is the oil usually introduced?

119. Are there any oil burners in which the oil is introduced in the front end of the fire-box?

120. Name some of the advantages of such a system.

121. What is combustion?

122. What is one of the main factors in combustion?

123. Of what is air composed?

124. In what proportion are these two gases combined?

125. What are the principal constituents of coal and other fuels?

126. What other valuable constituent is contained in bituminous coal?

127. What is the usual temperature of a boiler furnace when in active operation?

128. About what should be the temperature of the escaping gases?

129. What two factors are indispensable in the economical use of coal?

130. What is heat?

131. What is the first law of Thermodynamics?

132. What is the heat unit?

133. What is the mechanical equivalent of heat?

134. How many heat units are there in one pound of carbon?

135. How many heat units are there in one pound of hydrogen gas?

136. What is specific heat?

137. What is sensible heat?

138. What is latent heat?

139. Is the latent heat imparted to a body lost?

140. What is meant by the total heat of evaporation?

141. How much heat expressed in heat units is re-

quired to evaporate one pound of water from a temperature of 32° into steam at atmospheric pressure?

142. Name the two elements composing pure water.

143. In what proportion are these two gases combined in the formation of water?

144. Is perfectly pure water desirable for use in steam boilers?

145. What causes scale to form in boilers?

146. What proportion of mineral matter is usually found in water?

147. At what temperature does water show its greatest density?

148. What is steam?

149. Of what does matter consist?

150. How does the application of heat to any substance affect its molecules?

151. In what particular manner does heat affect the molecules of water?

152. Is steam under pressure visible?

153. What is saturated steam?

154. What is dry steam?

155. What is superheated steam?

156. What is meant by the term total heat in steam?

157. What is meant by the density of steam?

158. What is meant by the volume of steam?

159. What is the weight of a cubic foot of water at 39.1° temperature?

160. What is the weight of a cubic foot of water at a temperature of 212°?

161. What is the boiling point of water in the open air at sea level?

162. At what temperature will water boil in a perfect vacuum?

163. What is meant by the relative volume of steam?

In order that the student may get a general idea of the construction of a locomotive boiler, a sectional elevation of one is shown in Fig. 55.

The four vital organs of a locomotive boiler are: first, the fire-box A; second, the cylinder or barrel B-B; third, the flues or tubes C-C, and fourth, the smokestack D. Underneath the fire-box is suspended the ash pan E, next above the ash pan appears the mud ring F-F. This is a wrought iron bar bent to the proper form to extend around the bottom of the inside of the fire-box, the ends welded, and the ring thus formed is then drilled and riveted to the inside and outside sheets.

The fire-box is a rectangular box constructed of steel plates G-G from ⅜ to 9-16. in. in thickness. The inner shell is surrounded by an outside shell H-H, also constructed of steel plates, usually of about the same thickness as the inner plates. The outside shell is enough larger than the inside one to allow a space of 2½ to 4½ in. between the inner and outer plates. This space is called the water space and entirely surrounds the fire-box on the four sides, the water occupying it being in free communication with the main body of water in the boiler. It will thus be seen that the flat sides of the fire-box are subjected to the full pressure of the steam, and unless they be strengthened in some manner they will bulge apart. This danger is obviated by the use of staybolts J-J, Fig. 55. These are made of the best quality of wrought iron, generally from ⅞ to 1 1-16 in. in diameter, and have a screw thread cut their whole length. They

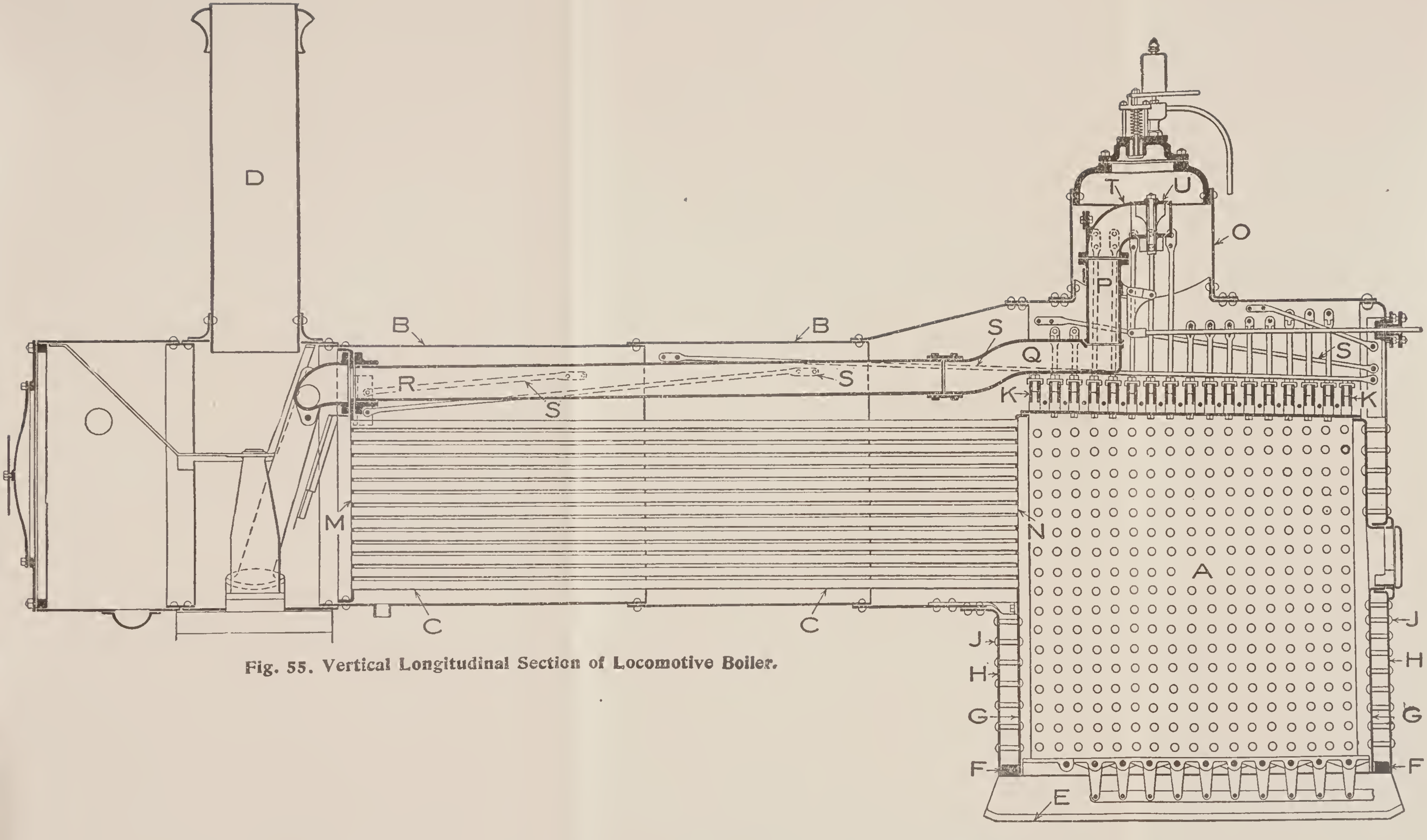


Fig. 55. Vertical Longitudinal Section of Locomotive Boiler.

are screwed through both the outside and inside plates at intervals of from 4 to 4½ in. apart center to center, thus securely binding the plates together. The projecting ends of these stay bolts are also riveted down onto the plates, thus further increasing their holding power.

Owing to the unequal expansion and contraction of the inner and outer plates, stay bolts are subjected to great strains and very frequently break, thereby causing a large amount of trouble. They should be made tubular, or at least have a small hole drilled into one end, as shown in Fig. 56, extending into the bolt a distance greater than the thickness of the outside plate, so that if the bolt breaks, which generally occurs next the outside plate, the water will escape through the fracture into the hole and thus indicate the defect and the danger.

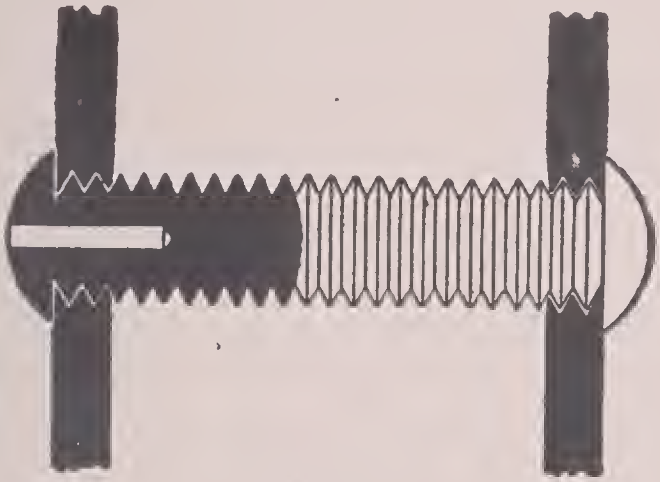


Fig. 56.

The Tate flexible stay bolt, which received the highest award at the St. Louis exposition in 1904, appears to offer at least a partial solution of the problem of staying fire-box sheets. Fig. 57 is a sectional view showing the design of this stay bolt. The ball-shaped head of the bolt C is inclosed within a socket formed by a sleeve B that screws into the outer sheet, and a cap A that screws onto the sleeve. The other end of the bolt is screwed into and through the fire sheet a sufficient distance to allow of riveting. It is apparent that the freedom of movement of the head of the bolt within its socket will allow the fire sheet to go and come, without subjecting the bolt to such severe strains and transverse stresses as would occur if the bolt were rigid. Fig. 58 is a full view of the bolt, except that the thread has not yet been cut on the end that screws into the fire sheet. The Tate flexible stay bolt is manufactured by the Flannery Bolt Company, Pittsburg, Pa.

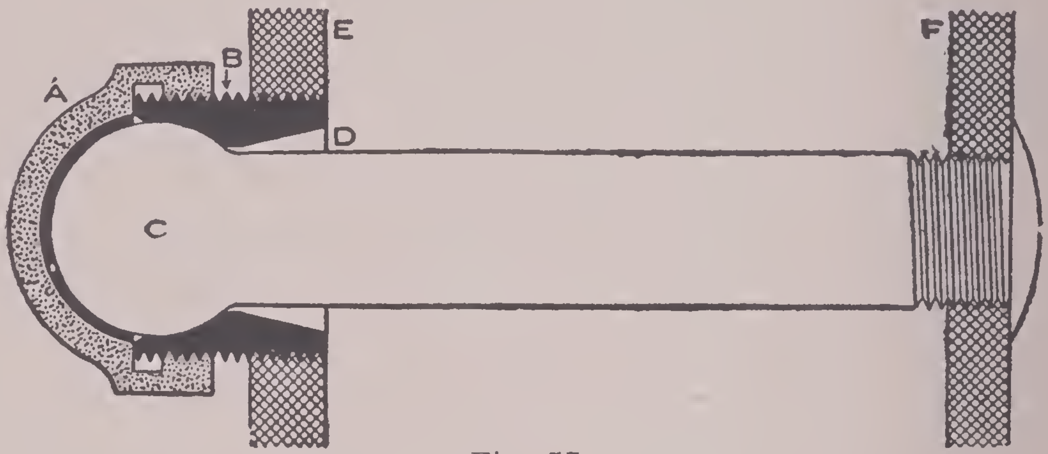


Fig. 57.

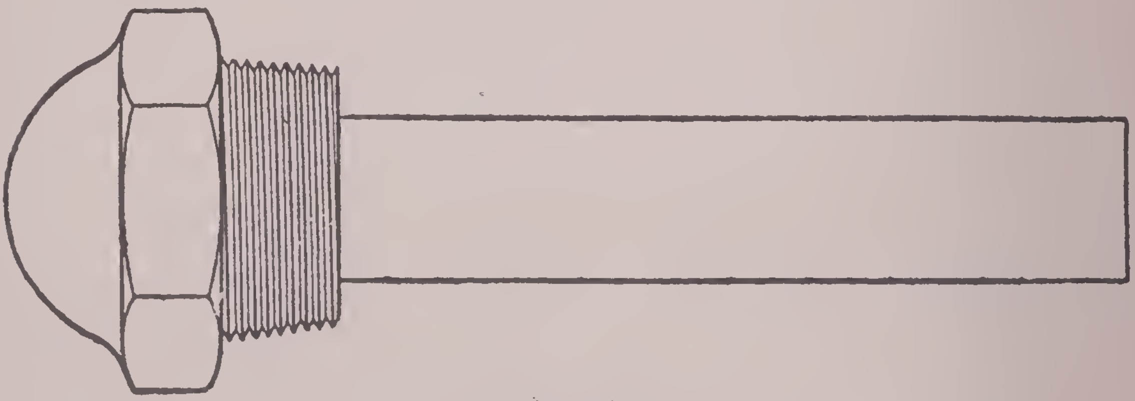


Fig. 58.

SHAFFER'S IMPROVED STAY BOLT.

Figs. 59 to 62, inclusive, illustrate an improved stay bolt for locomotive boilers invented and patented by Mr. D. L. Shaffer, of Pittsburg, Pa., which he claims will overcome the dangers incident to contraction and expansion of the sheets.

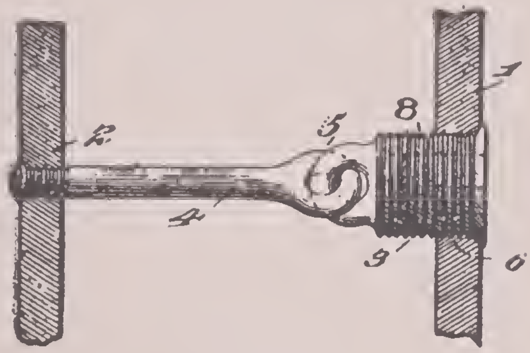


Fig. 59.

Mr. Shaffer describes his invention as follows:

"One of the difficulties in the use of steam boilers is the constant contraction and expansion to which the same are subjected in use, and as a consequence the stay bolts are subjected to a constant warping or bending strain in opposite directions. This results in breaking the bolts close to one of the sheets to which the bolts are attached.

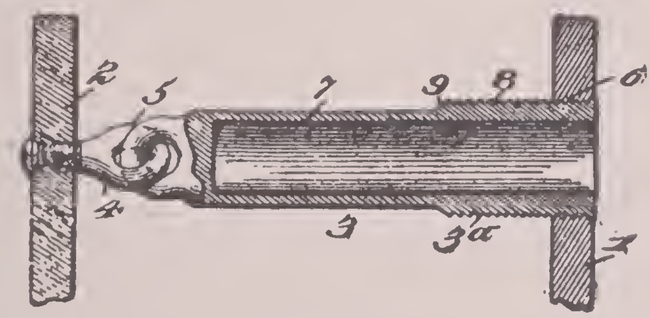


Fig. 60.

"The object of my invention is to provide a stay bolt for steam boilers wherein the above objection is overcome. To this end the bolt is made flexible—that is, of two sections suitably joined together, so that they can move relatively to each other, each section being provided at its ends with means of securing it to the sheet. . . .

"In the accompanying drawings, Fig. 59 is a side view of one form of my improved stay bolt. Fig. 60 is a modification thereof to provide increased heating capacity to the boiler, and Fig. 61 is still another modification showing a different form of joint. Fig. 62 is another modification in which the large end is threaded the entire length.

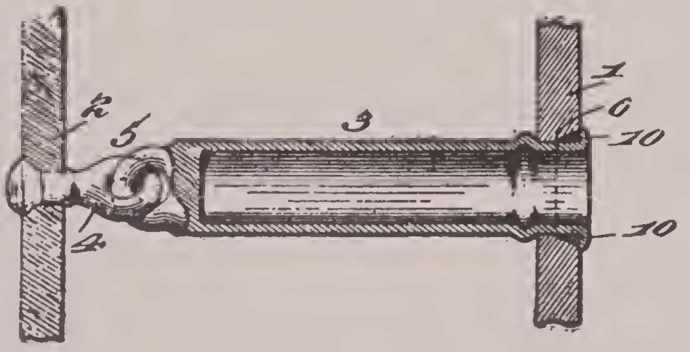


Fig. 61.

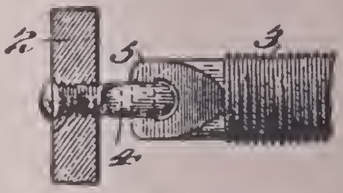


Fig. 62.

"In the drawings the sheets which are connected by the stay bolts are shown at 1 and 2. The stay bolt is made of two sections 3 and 4, which are suitably jointed to each other, so that they can move at least a limited amount in all directions. Various forms of joints may be employed, that shown in the drawings being a simple and efficient one and comprises an eye 5, formed on the ends of each joint, which eyes interlock, as shown, so as to form, in effect, a knuckle-joint. This joint, however, prevents independent rotary movement of the two sections, so that the bolt can be screwed into place by turning on one end thereof. This knuckle-joint is necessarily of considerable size, and as a consequence the hole in one of the sheets must be made sufficiently large to permit the entrance of the bolt. This is clearly shown in the drawings, where in the hole 6 in the sheet 1 is made quite large and the section 3 of the bolt is made of a size sufficient to fill this hole. When it is desired to increase the heating capacity of the furnace, the large section 3 of this bolt can be made very long, as shown in Fig. 60 and hollow as shown at 7, thus forming in effect a tubular stay bolt, open at its inner end to the furnace, so that the flame and heat can enter said tube, and thus increase the heating surface of the fire-box.

"Each section is provided with suitable means at its ends for securing the bolt to the sheets.

"As shown in Figs. 59 and 60, both sections are provided with threaded ends 8, for screwing into the holes in the sheets. The outer end of the large tubular section 3a (shown in Fig. 60) is slightly enlarged where the screw threads are formed, as shown at 9, to obviate the necessity of threading the said section through its entire length.

"Various other forms of attaching means to the flue sheets may be employed, as for instance in Fig. 61, the hole 6 in the sheet 1 is slightly reamed out on its outer surface and a small conical metallic thimble 10 is placed in said depression, surrounding the bolt section 3a, after which the end of the latter is expanded outwardly over said thimble, this thimble acting as a non-compressible packing ring for the joint. Fig. 62 is a modification in which the large section is threaded for its entire length. The knuckle-joint (shown at 5) permits the two bolt sections to move relatively to each other in all directions, so that unequal expansion and contraction of the boiler will not produce any bending strains in the metal of the bolt.

"As a consequence they will last much longer than an ordinary non-flexible bolt."

The following solemn reflections upon the stay bolt situation are reproduced from the Railway Master Mechanic:

"One of the peculiar things in locomotive operation that seems to thwart the best efforts of locomotive designers is the uncertain status of the stay bolt situation; erratic for the reason that like causes do not product like effects. The reasons for failure under similar conditions do not hold uniformly, and these facts are responsible for the inability to stem the wholesale breakages going on in locomotive fireboxes. Remedies are as plentiful as the leaves of Vallambrosa, and while some of these work out in specific cases, they fail miserably in general application.

"It would seem to be a simple mechanical achievement to provide a stay bolt that would be safe under any boiler pressure and condition of service, but the contrary is well known to be the actual case. After running the gamut of dimensions, co-efficients of expansion, moments of resistance and all other elements affecting the tendency of stay bolts to rupture—they break. Is it due to rigidity, to quality of material, to want of perforation for air admission, or all three of these points that are urged as inimical to the life of a stay bolt? These questions are pertinent when stay bolt failures are a matter of constant record on some roads, and of infrequent occurrence on others.

"This line of thought is suggested by the wholesale failure of stay bolts on a French engine which was built for a prominent road in this country. The breakages began to be noted when the engine had made a mileage much less than when this trouble would be expected to develop on an American engine having a similar design of bolt—which was rigid, by the way, and of copper, in a copper fire-box sheet. The destruction went on until fully one-half of the original installation was replaced. It is possible that the narrow water spaces of foreign practice had some influence in producing this result, yet the fact remains that this firebox and its staying was constructed on lines in strict accord with the practice of the French builders of the engine—which has proved a remarkable machine in other respects, there as well as here, and the short and unsatisfactory life of the bolts in this country causes one to marvel, when it is known that this identical practice obtains abroad, and without tidings of similar failures reaching this country. The application of flexible stay bolts to the above engine might work a reformation in failures."

STRESSES IN STAY BOLTS.

Ordinary practice spaces stay bolts four inches from center to center, thus giving an area of 4x4, equals 16 square inches of surface to be supported by each bolt. This does not take into account the area of the bolt itself.

Assuming a boiler pressure of 200 pounds per square inch, the load to be carried by each bolt will be 16x200, equals 3,200 pounds.

The bolts being one inch in diameter and threaded 12 per inch, have a diameter at the bottom of the thread of

.892 inch. This leaves a net area of .625 inch, and with wrought iron having a T. S. of 50,000 pounds per square inch as the material for stay bolts, the net strength of each bolt will be 50,000x.625, equals 31,250 pounds, which leaves a factor of safety of 31,250, divided by 3,200, equals 9.76.

The above calculation appears to be, and is, simple enough, for the reason that all of the elements considered are positive, and the only force provided for is the straight pull on the bolt. The situation, however, becomes extremely complex when expansive forces tend to rupture the bolt by alternating transverse stresses due to the bending moment which is the effect of the tendency of the inside sheet to move by expansion. In order to treat the case by the principle of moments it will be necessary, in the absence of reliable data, to assume some value for the force exerted on the inside sheet, and for our purpose 200 pounds will be taken, which may be too much or too little. A water space of four inches in width is common practice at this time, and the force of 200 pounds acting through a lever arm of four inches produces a bending moment of:

$$M=200\times4=800 \text{ inch-pounds.}$$

The resisting moment R for a solid cylinder$=0.0982d^3$, and since the diameter of a one-inch bolt at bottom of thread is 0.892 inch, $R=0.069$. By the equation $\frac{M}{R}$, the stress at the outermost fibres of the bolt is:

$$S=\frac{M}{R}=\frac{800}{0.69}=11590 \text{ pounds per square inch, due to}$$

the vibratory action of the firebox. It is seen that this stress alone is quite sufficient to produce rupture when repeated indefinitely, but the bolt is also resisting a pull of 5,120 pounds per square inch, and since these stresses both tend to break the bolt, the total effect in the direction of rupture is $5,120+11,590=16,710$ pounds per square inch, which is entirely too high when constantly reversed. There is only one unknown quantity in the factors used, namely, the assumed load of 200 pounds acting on the fire-box side. The theoretical deflection for that load $=\frac{Wl^3}{3EI}$ is too little for consideration, and for that reason the forces operating to bend the bolt are believed to be much higher than the value taken in the calculations.

It is plain that a rigid stay bolt can not stand such treatment even when made of the best material, and if the foregoing assumptions are correct, the reason why flexibility is the first essential in a stay bolt is equally plain. Mohler and Spangenberg have given us the results of experiments made to show the effect, or rapid weakening of metal under repeated reversal of loads, and their findings would appear to be very applicable to the life of stay bolts.

THE CROWN SHEET AND RADIAL STAYS.

It is also necessary to strengthen the flat top or crown sheet of the fire-box. There are three common methods by which this is done: first, by crown bars; second, by radial stays, and third, by the Belpaire system.

In Fig. 55 the crown bar method is shown, K-K being the ends of the crown bars. Fig. 63 is a transverse sectional view of the same boiler, and one of the crown bars, K-K, is shown extending across the top of the fire-box above the crown sheet and supported at the ends

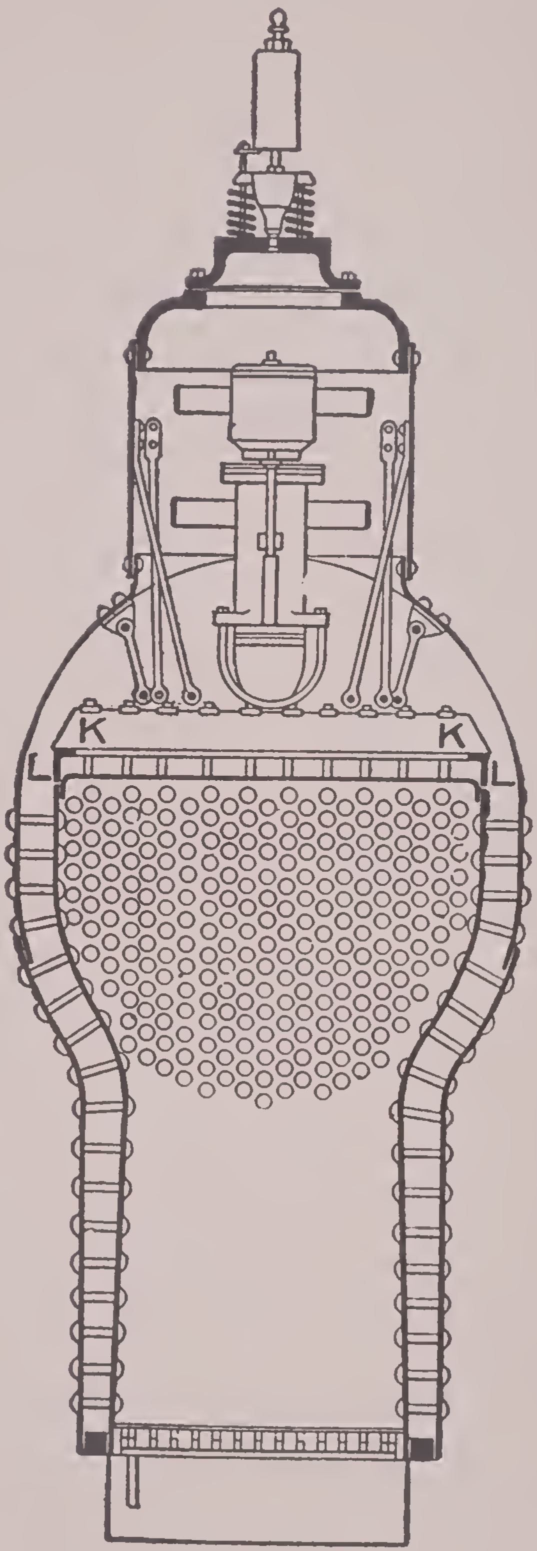


Fig. 63.

by special castings that rest on the edges of the side sheets and on the flange of the crown sheet at L-L. These crown bars are double girders, and a space is allowed between them and the top of the crown sheet to allow the water to circulate freely. At intervals of 4 or 5 inches crown bolts are placed having the head inside the fire-box and the nut bearing on a plate on top of the crown bar. There is also a thimble or ring for each bolt to pass through, between the top of the crown sheet and the bottom of the crown bars. These thimbles maintain the proper distance between the crown sheet and the crown bars.

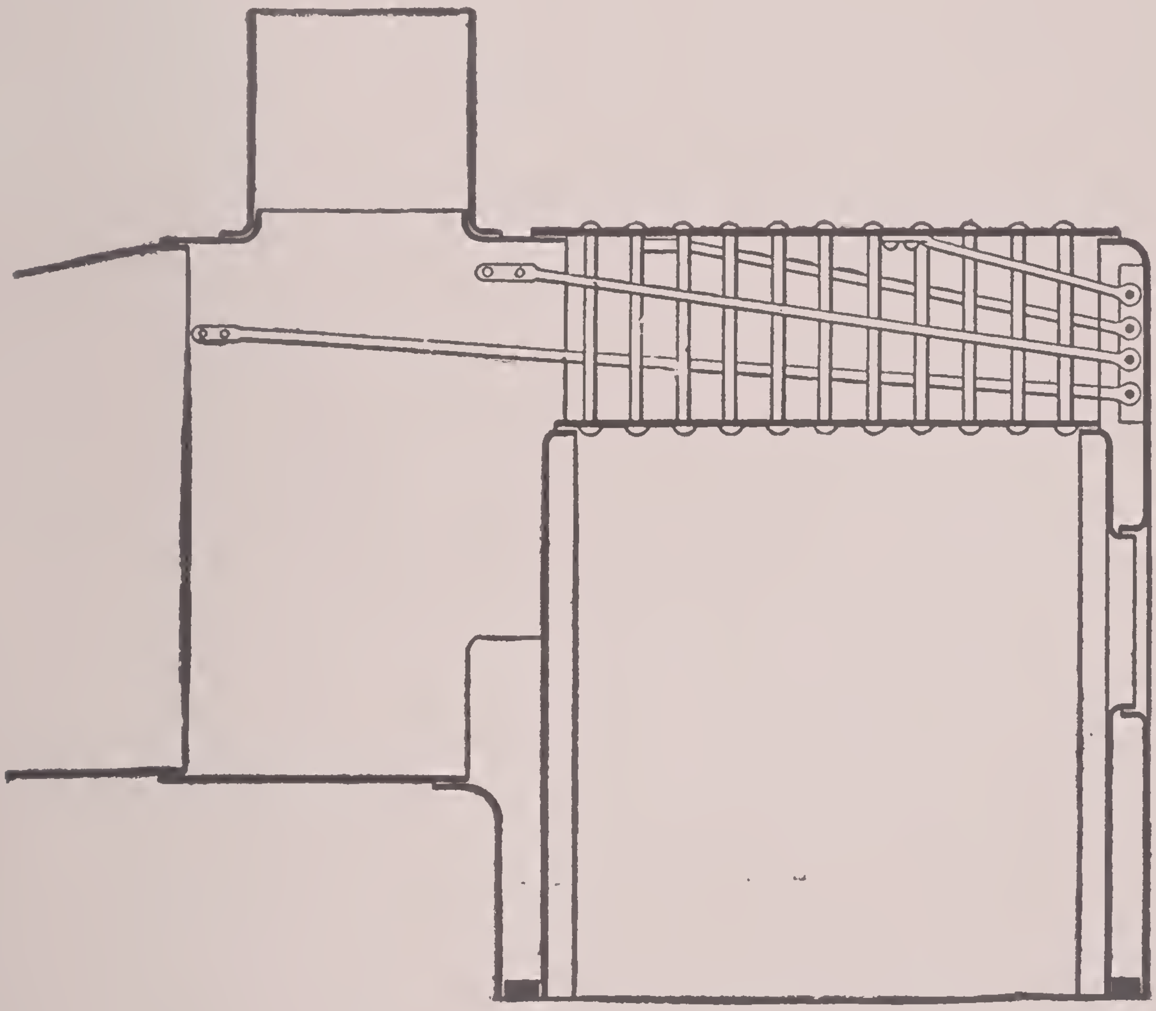


Fig. 64.

The second method of supporting the crown sheet is by the use of radial stays, which are long stay bolts screwed into the outer shell and into the crown sheet. Fig. 64

shows a longitudinal section of a fire-box having the crown sheet secured by radial stays, and Fig. 65 is a transverse section and back view of the same. The principal defect in this construction is, that in order to resist successfully the strains induced by the pressure on the crown sheet, the stays should be placed at right angles to its surface, and in order to resist the pressure on the outer shell they should be radial to its cylindrical form, but as it is impossible to so locate them the strains are not equally divided and a certain distortion of both the stays and the sheets is the result. The only thing that can be

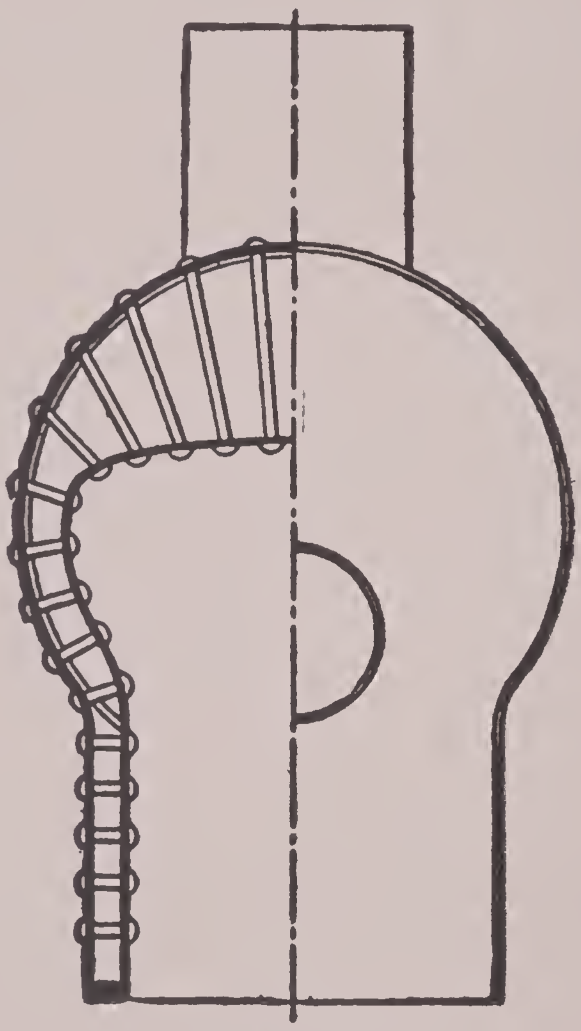


Fig. 65.

done under such conditions is to approximate as closely as possible the correct position of the stays.

In the third or Belpaire system the outside shell of the boiler directly over the crown sheet is made flat to conform to the surface of the crown sheet. This permits of positive staying, the stays all having good bearings in and on the sheets. This method is illustrated by Figs. 66 and 67, which shows longitudinal and transverse sections of this form of fire-box. The long stays S S S are seen to be connected at right angles to the flat plates, and the sides, which are also flat, are braced by the rods B B B extending across from side to side. A great ad-

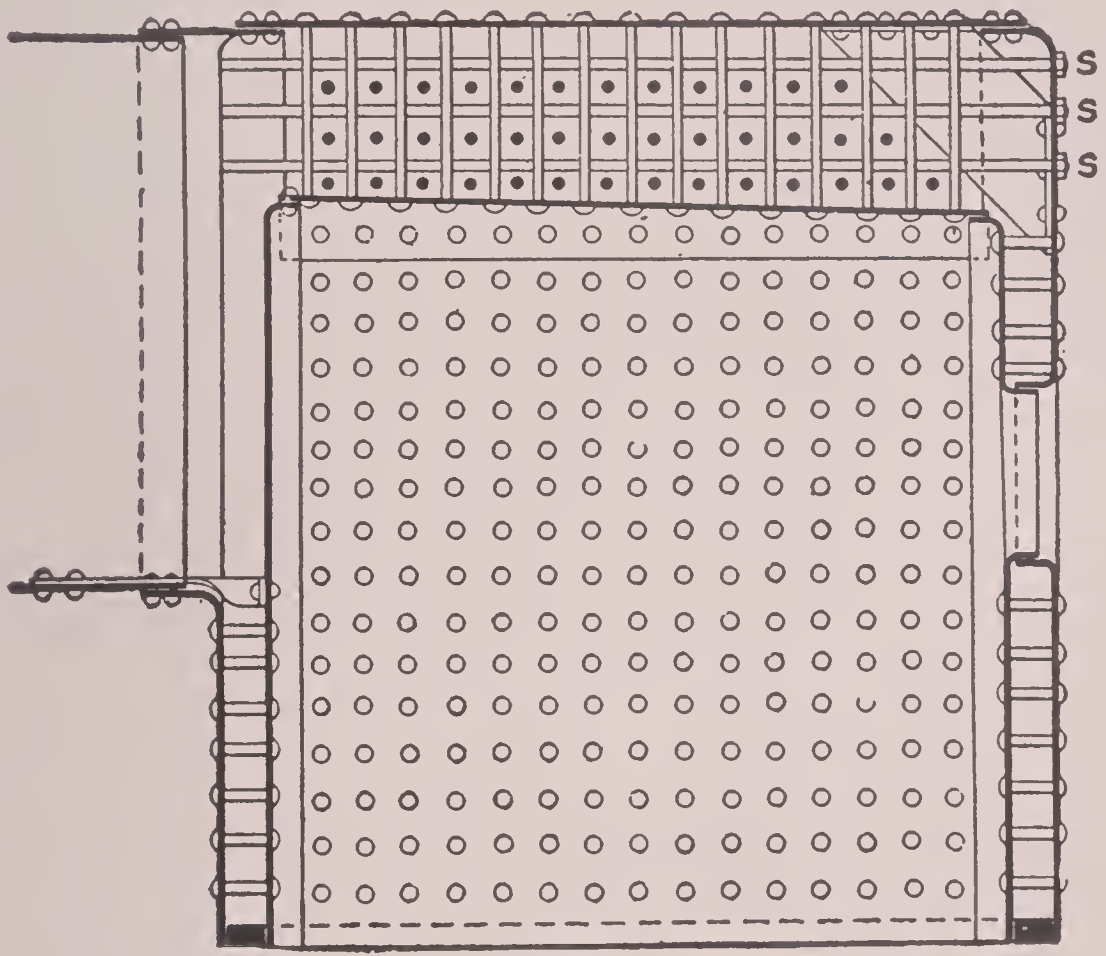


Fig. 66.

vantage in this form of fire-box is that the crown sheet and the flat outside sheet directly over it have more or less flexibility and are free to bend or spring, according as the inside plates become heated and expand, or cool and contract. On the other hand, if the outside sheet is cylindrical in shape and has the crown sheet stayed to it by means of radial stays, it will be subjected to excessive distortional strains caused by the more or less pushing upwards of the stays as the inner plates become heated.

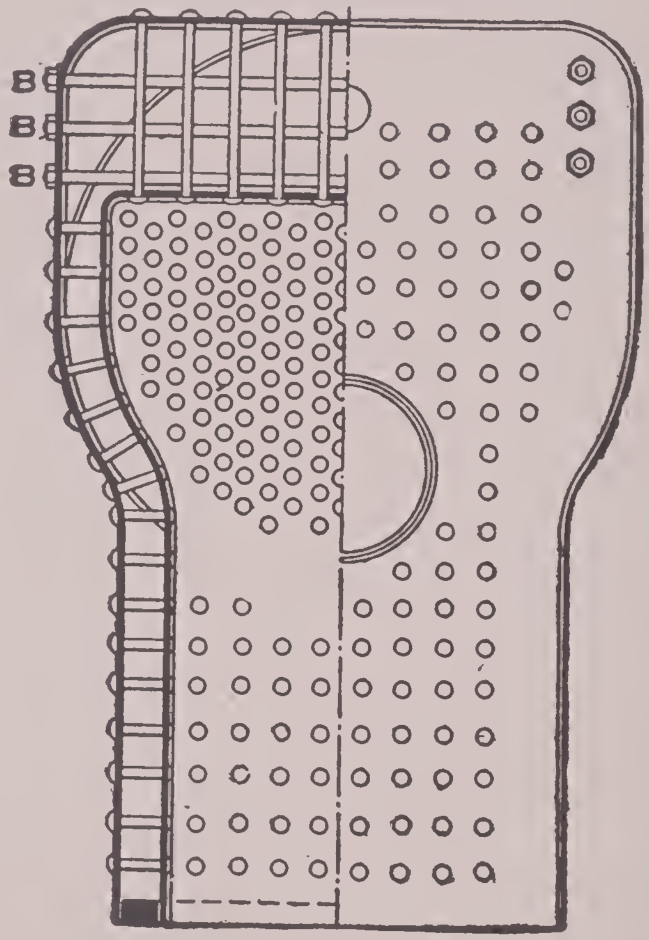


Fig. 67.

The crown sheets of locomotive boilers are as a rule made to slope downwards from the front end of the fire-box toward the back end, so as to be several inches lower behind than in front. This is done in order to lessen the danger of the back end of the crown sheet becoming uncovered of water in running down a steep grade. There is not so much danger of the front end of the crown sheet becoming uncovered, either in going up or down a grade, for the reason that it is nearer the center of the length of the boiler.

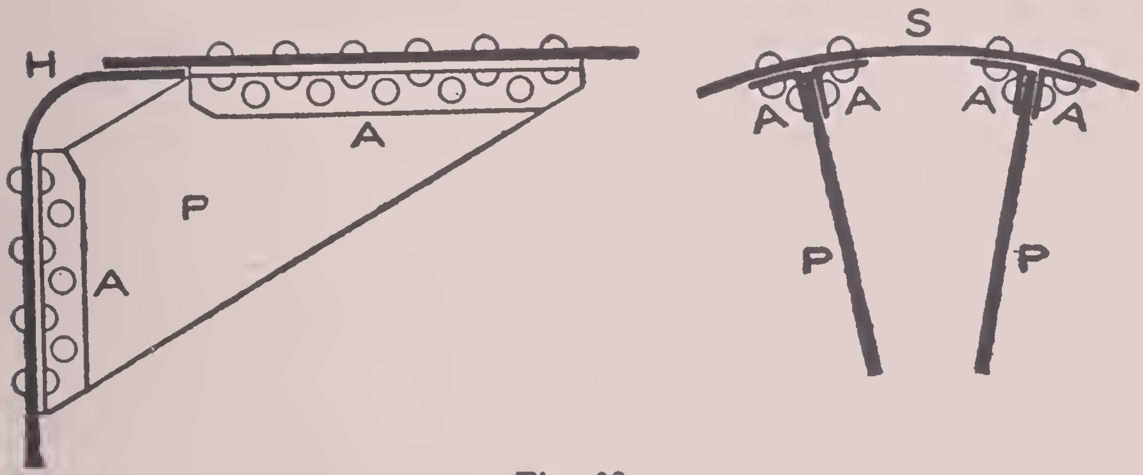


Fig. 68.

The usual method of staying the heads of locomotive boilers is illustrated in Fig. 55. Diagonal stays or braces S S S S are used, having one end riveted to the shell and the other end connected to that portion of the head that needs bracing.

The flues serve to brace the flue sheet and all of that portion of the front head to which they are connected. Sometimes gusset stays are used for staying the heads. A gusset stay is a triangular piece of boiler plate P, Fig. 68, connected to the boiler head H and to the shell S by means of angle irons A A A A, which are riveted to the head. The plate P is connected to the angle irons by rivets. The tube plates or flue sheets are of necessity thicker than the shell, owing to the fact that they are considerably weakened by the holes drilled in them for the tubes. By reference to Fig. 55 the arrangement of tubes will be clearly understood, N being the fire-box end and M the smoke-box end. Fig. 63 gives a view of the fire-box end of the tubes, which in this case are arranged in vertical rows. In some cases the tubes are placed in horizontal rows. Opinions differ as to the best arrangement, but it is generally conceded that the plan of having them in vertical rows permits of a freer circulation of the water around them.

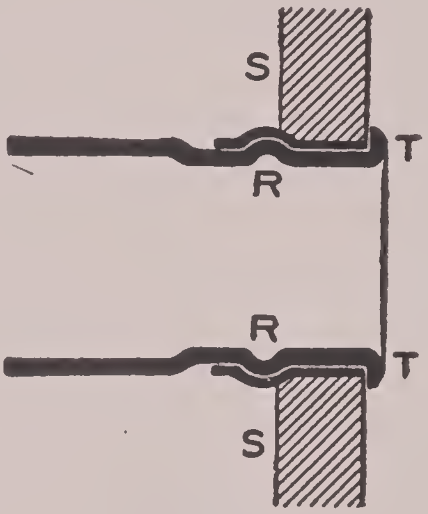


Fig. 69.

The diameter of locomotive tubes is usually two inches, as that size has been found by experience to be the most suitable for the distribution of the hot gases on their way from the fire-box to the smoke-stack.

The tubes or flues are made water-tight in the sheets by being expanded in the holes drilled to receive them. The ends of the tubes are allowed to project through the sheets ¼ inch or more. Copper ferrules are generally slipped in over the outside of the tubes, and the tube is then expanded to fill the hole and a water-tight joint is thus secured. After the tube has been sufficiently expanded, the projecting end is turned back onto the sheet and formed into a bead by the use of a caulking tool made especially for the purpose. Fig. 69 is a sectional view of one end of a tube as it appears after being expanded into the sheet.

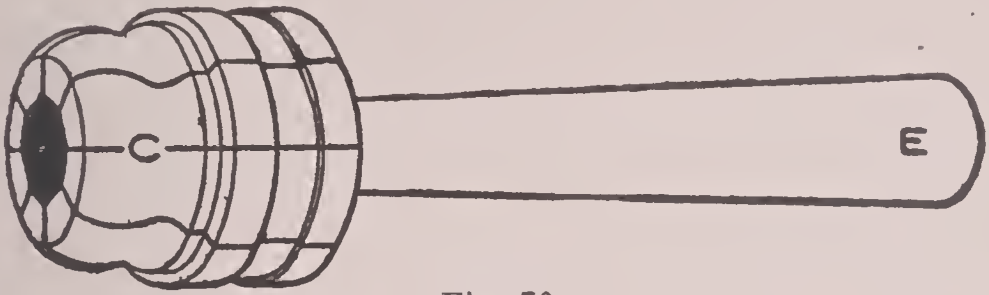


Fig. 70.

There have been various types of tools designed and made for expanding tubes, but the two most generally used are the Prosser, Figs. 70 and 71, and the Dudgeon, Fig. 72.

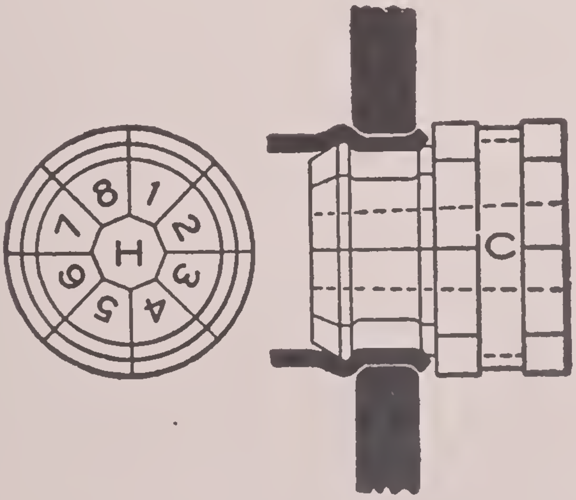


Fig. 71.

The Prosser tube expanded is an expanding plug made up of eight or more sectors, 1, 2, 3, 4, 5, 6, 7, 8, held together by an open steel ring or spring clasp C (see Fig.

71). The sector-shaped pieces have their inner edges cut away in such a shape as to leave a tapered hole H through the center of the plug. Into this hole the tapered mandrel E is inserted, and when the expander is inserted into the mouth of the tube and the mandrel driven in, the sectors will be slightly separated and the tendency will be to expand the tubes. The outside conformation of the sectors composing the plug is such that, when the tube is expanded, it not only completely fills the hole in the tube sheet but is also expanded past the edge of the hole, both on the inside and outside of the sheet, thus securely binding the tube in the sheet and causing it to act as a brace. Referring to Fig. 69, S S is the tube sheet, R R shows the expanded ridge on the tube inside the sheet, and T T indicates the manner in which the end of the tube is expanded and beaded over onto the outer edge of the hole.

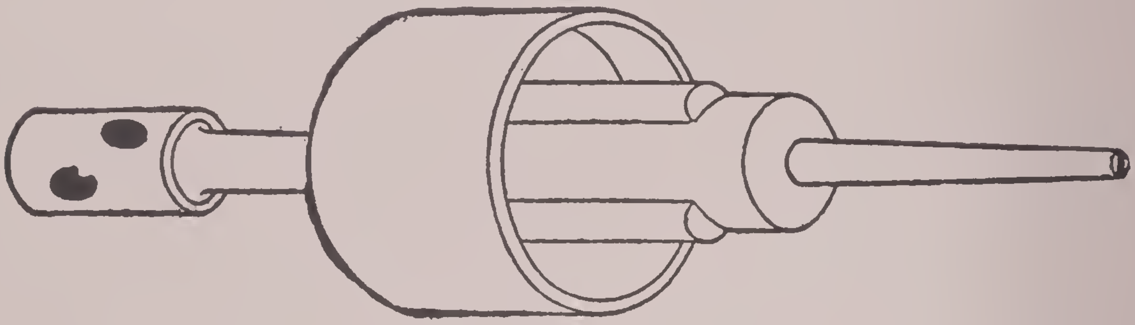


Fig. 72.

The Dudgeon roller tube expander, shown in Fig. 72, consists of a hollow plug having a sleeve or cap at one end that bears against the outside of the sheet, thus serving as a guide to the roller when in use. Three cavities are cut longitudinally in the plug, and into each one of these cavities a roller is inserted which is free to revolve. These rollers can also move a short distance outward from the center of the plug. In using this expander the plug is inserted into the mouth of the tube as far as the cap will permit. A tapered mandrel is then driven into the central opening, and the rollers are forced out against the inner surface of the tube. The mandrel is then slowly turned around by means of a short steel rod inserted into one of the holes shown in the head (see Fig. 72). This causes the plug to revolve, as well as the rollers which bear hard against the tube, and expand it so as to fill the hole in the sheet.

The Dudgeon expander is also a very efficient tool for repairing leaky tubes. Cast iron or steel ferrules made slightly tapering are sometimes driven into the mouths of tubes after they have been expanded, but this method, although it may serve to prevent leakage, will at the same time decrease the capacity of the tubes to conduct the heat.

As the term tensile strength (T. S.) will be used quite frequently in the remaining portion of this chapter, it is proper that its meaning be explained for the benefit of the beginner.

The expression tensile strength per square inch as referring to a boiler sheet means that when the plate is rolled, and before it is accepted by the inspector, a small test piece having a sectional area of one square inch is cut from the plate and placed in a testing machine, where it is subjected to a pull or strain in the direction of its length, and this strain must equal the T. S. called for in the specifications. If the specifications call for a T. S. of 66,000 pounds per square inch, the test piece must withstand that much of a strain before showing signs of breaking, otherwise the sheet will or should be rejected.

When steel was first introduced as a material for boiler plate, it was customary to demand a high tensile strength, 70,000 to 74,000 pounds per square inch, but experience and practice demonstrated in course of time that it was much safer to use a material of lower tensile strength. It was found that with steel boiler plate of high tenacity there was great liability of its cracking, and also of certain changes occurring in its physical properties, brought about by the variations in temperature to which it was exposed. Consequently present-day specifications for steel boiler plate call for tensile strengths running from 55,000 to 66,000 pounds, usually 60,000 pounds per square inch. Dr. Thurston gives what he calls "good specifications" for boiler steel as follows: Sheets to be of uniform thickness, smooth finish, and sheared closely to size ordered. Tensile strength to be 60,000 pounds per square inch for fire-box sheets and 55,000 pounds per square inch for shell sheets. Working test: a piece from each sheet to be heated to a dark cherry red, plunged into water at 60° and bent double, cold, under the hammer. Such piece to show no flaw after bending." The U. S. Board of Supervising Inspectors of Steam Vessels prescribes, in Section 3 of General Rules and Regulations, the following method for ascertaining the tensile strength of steel plate for

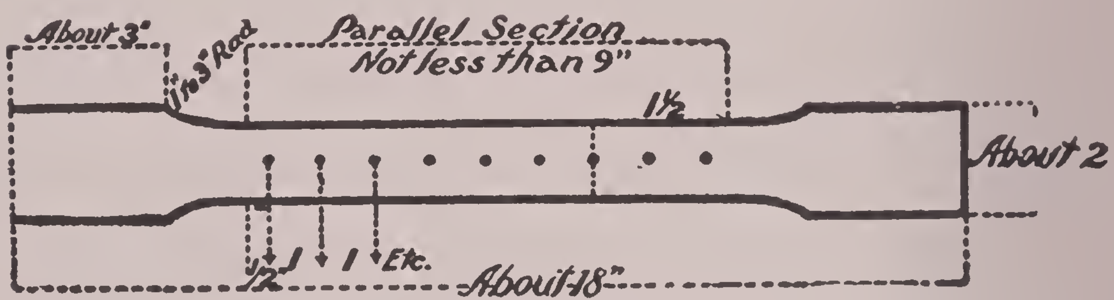


Fig. 73. Test Piece.

boilers: "There shall be taken from each sheet to be used in shell or other parts of boiler which are subject to tensile strain, a test piece prepared in form according to the following diagram:

The straight part in center shall be 9 inches in length and 1 inch in width, marked with light prick punch marks at distances 1 inch apart, as shown, spaced so as to give 8 inches in length. The sample must show, when tested, an elongation of at least 25 per cent. in a length of 2 inches for thickness up to ¼ inch inclusive; in a length of 4 inches, for over ¼ inch to 7-16 inch inclusive; in a length of 6 inches, for all plates over 7-16 inch and under 1¾ inches in thickness. The samples shall also be capable of being bent to a curve of which the inner radius is not greater than 1½ times the thickness of the plates, after having been heated uniformly to a low cherry red and quenched in water of 82° F."

PUNCHED AND DRILLED PLATES.

Much has been written on this subject, and it is still open for discussion. If the material is a good, soft steel, punched sheets are apparently as strong and in some instances stronger than drilled; especially is this the case with regard to the shearing resistance of the rivets, which is greater with punched than with drilled holes.

Concerning rivets and rivet iron and steel Dr. Thurston has this to say in his "Manual of Steam Boilers": "Rivet iron should have a tenacity in the bar approaching 60,000 pounds per square inch, and should be as ductile as the very best boiler plate when cold. A good ⅝-inch iron rivet can be doubled up and hammered together cold without exhibiting a trace of fracture." The shearing resistance of iron rivets is about 85 per cent. and that of steel rivets about 77 per cent of the tenacity of the original bar, as shown by experiments made by Greig and Eyth. The researches made by Wöhler demonstrated that the shearing strength of iron was about four-fifths of the tensile strength.

The tables that follow have been compiled from the highest authorities and show the results of a long and exhaustive series of tests and experiments made in order to ascertain the proportions of riveted joints that will give the highest efficiencies.

The following table gives the diameters of rivets for various thicknesses of plates and is calculated according to a rule given by Unwin.

TABLE 5

TABLE OF DIAMETERS OF RIVETS*

Thickness of Plate	Diameter of Rivet	Thickness of Plate	Diameter of Rivet
1/4 inch	1/2 inch	9/16 inch	7/8 inch
5/16 "	9/16 "	5/8 "	15/16 "
3/8 "	11/16 "	3/4 "	1 1/16 "
7/16 "	3/4 "	7/8 "	1 1/8 "
1/2 "	13/16 "	1 "	1 1/4 "

The efficiency of the joint is the percentage of the strength of the solid plate that is retained in the joint, and it depends upon the kind of joint and method of construction.

If the thickness of the plate is more than ½ inch. the joint should always be of the double butt type.

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*Machine design—W. C. Unwin.

The diameters of rivets, rivet holes, pitch and efficiency of joint, as given in the following table, which was published in the "Locomotive" several years ago, were adopted at the time by some of the best establishments in the United States.*

Table 6

Proportions and Efficiencies of Riveted Joints

	Inch	Inch	Inch	Inch	Inch
Thickness of plate	1/4	5/16	3/8	7/16	1/2
Diameter of rivet	5/8	11/16	3/4	13/16	7/8
Diameter of rivet-hole	11/16	3/4	13/16	7/8	15/16
Pitch for single riveting	2	2 1/16	2 1/8	2 3/16	2 1/4
Pitch for double riveting	3	3 1/8	3 1/4	3 3/8	3 1/2
Efficiency—single-riveted joint	.66	.64	.62	.60	.58
Efficiency—double-riveted joint	.77	.76	.75	.74	.73

Concerning the proportions of double-riveted butt joints, Professor Kent says: "Practically it may be said that we get a double-riveted butt joint of maximum strength by making the diameter of the rivet about 1.8 times the thickness of the plate, and making the pitch 4.1 times the diameter of the hole."

Table 7, as given below, is condensed from the report of a test of double-riveted lap and butt joints.† In this test the tensile strength of the plates was 56,000 to 58,000 pounds per square inch, and the shearing resistance of the rivets (steel) was about 50,000 pounds per square inch.

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*Thurston's Manual of Steam Boilers.

†Proc. Inst. M. E., Oct., 1888.

TABLE 7

DIAMETER AND PITCH OF RIVETS—DOUBLE-RIVETED JOINT

Kind of Joint	Thickness of Plate	Diameter of Rivet	Ratio of Pitch to Diameter
Lap	3/8 inch	0.8 inches	3.6 inches
Butt	3/8 "	0.7 "	3.9 "
Butt	3/4 "	1.1 "	4.0 "
Butt	1 "	1.3 "	3.9 "

Lloyd's rules, condensed, are as follows:

LLOYD'S RULES—THICKNESS OF PLATE AND DIAMETER OF RIVETS

Thickness of Plate	Diameter of Rivets	Thickness of Plate	Diameter of Rivets
3/8 inch	5/8 inch	3/4 "	7/8 inch
7/16 "	5/8 "	13/16 "	7/8 "
1/2 "	3/4 "	7/8 "	1 "
9/16 "	3/4 "	15/16 "	1 "
5/8 "	3/4 "	1 "	1 "
11/16 "	7/8 "		

The following table 8 is condensed from one calculated by Professor Kent,* in which he assumes the shearing strength of the rivets to be four-fifths of the tensile strength of the plate per square inch, and the excess strength of the perforated plate to be 10 per cent.

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*Kent's Mechanical Engineer's Pocket-Book, page 362.

TABLE 8

Thickness of Plate	Diameter of Hole	Pitch		Efficiency	
		Single Riveting	Double Riveting	Single Riveting	Double Riveting
Inches	Inches	Inches	Inches	Per Cent	Per Cent
3/8	7/8	2.04	3.20	57.1	72.7
7/16	1	2.30	3.61	56.6	72.3
1/2	1	2.14	3.28	53.3	70.0
1/2	1 1/8	2.57	4.01	56.2	72.0
9/16	1	2.01	3.03	50.4	67.0
9/16	1 1/8	2.41	3.69	53.3	69.5
9/16	1 1/4	2.83	4.42	55.9	71.5
5/8	1	1.91	2.82	47.7	64.6
5/8	1 1/8	2.28	3.43	50.7	67.3
5/8	1 1/4	2.67	4.10	53.3	69.5

Another table of joint efficiencies as given by Dr. Thurston* is as follows, slightly condensed from the original calculation:

TABLE 9

Single riveting

Plate thickness.	**5/16''**	**3/8''**	**7/16''**	**1/2''**	**5/8''**	**3/4''**	**7/8''**	**1''**
Efficiency	**.55**	**.55**	**.53**	**.52**	**.48**	**.47**	**.45**	**.43**

Double riveting

Plate thickness.	3/8''	7/16''	1/2''	3/4''	7/8''	1''
Efficiency......	.73	.72	.71	.66	.64	.63

The author has been at considerable pains to compile Tables 10, 11 and 12, giving proportions and efficiencies of single lap, double lap and butt, and triple-riveted butt joints. The highest authorities have been consulted in the computation of these tables and great care exercised in the calculations.

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*Thurston's Manual of Steam Boilers, page 119.

TABLE 10

PROPORTIONS OF SINGLE-RIVETED LAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Efficiency Per Cent
5/16	9/16	1.13	50.5
"	5/8	1.33	53.3
"	11/16	1.55	55.7
3/8	3/4	1.60	53.3
"	7/8	2.04	57.1
7/16	7/8	1.87	53.2
"	1	2.30	56.6
1/2	1	2.14	53.3
"	1 1/8	2.57	56.2
9/16	1	2.01	50.4
"	1 1/8	2.41	53.3
"	1 1/4	2.83	55.9
5/8	1 1/8	2.28	50.7
"	1 1/4	2.67	53.3

It will be noticed that in single-riveted lap joints the highest efficiencies are attained when the diameter of the rivet hole is about 2⅓ times the thickness of the plate, and the pitch of the rivet 2⅜ times the diameter of the hole.

With the double-riveted joint it appears, according to Table 11, that in order to obtain the highest efficiency the joint should be designed so that the diameter of the rivet hole will be from 1 4-5 to 2 times the thickness of plate, and the pitch should be from 3⅓ to 3½ times the diameter of the hole. Concerning the thickness of plates Dr. Thurston has this to say:* "Very thin plates cannot be well caulked, and thick plates cannot be safely riveted. The limits are about ¼ of an inch for the lower limit, and ¾ of an inch for the higher limit." The riveting machine, however, overcomes the difficulty with very thick plates.

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*Thurston's Manual of Steam Boilers, page 120.

The triple-riveted butt joint with two welts, one inside and one outside, has two rows of rivets in double shear and one outer row in single shear on each side of the butt, the pitch of rivets in the outer rows being twice the pitch of the inner rows. One of the welts is wide enough for the three rows of rivets each side of the butt, while the other welt takes in only the two close pitch rows.

TABLE 11

PROPORTIONS OF DOUBLE-RIVETED LAP AND BUTT JOINTS

Thickness of Plate	Diameter of Rivet	Pitch of Rivet	Efficiency
5/16 inch	9/16 inch	1.71 inches	67.1 per cent
5/16 "	5/8 "	2.05 "	69.5 "
3/8 "	3/4 "	2.46 "	69.5 "
3/8 "	7/8 "	3.20 "	72.7 "
7/16 "	3/4 "	2.21 "	66.2 "
7/16 "	7/8 "	2.86 "	69.4 "
7/16 "	1 "	3.61 "	72.3 "
1/2 "	1 "	3.28 "	70.0 "
1/2 "	1 1/8 "	4.01 "	72.0 "
9/16 "	1 "	3.03 "	67.0 "
9/16 "	1 1/8 "	3.69 "	69.5 "
9/16 "	1 1/4 "	4.42 "	71.5 "
5/8 "	1 1/8 "	3.43 "	67.3 "
5/8 "	1 1/4 "	4.10 "	69.5 "
3/4 "	1 "	2.50 "	72.0 "
7/8 "	1 1/8 "	3.94 "	74.2 "
1 "	1 1/4 "	4.10 "	76.1 "

When properly designed, this form of joint has a high efficiency, and is to be relied upon. Table 12 gives proportions and efficiencies, and it will be noted that the highest degree of efficiency is shown when the diameter of rivet hole is from 1¼ to 1½ times the thickness of plate, and the pitch of the rivets is from 3½ to 4 times the diameter of the hole. This, of course, refers to the pitch of the close rows of rivets, and not the two outer rows.

TABLE 12

PROPORTIONS OF TRIPLE-RIVETED BUTT JOINTS WITH INSIDE AND OUTSIDE WELT

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Pitch of Outer Rows Inches	Efficiency Per Cent
3/8	13/16	3.25	6.5	84
7/16	13/16	3.25	6.5	85
1/2	13/16	3.25	6.5	83
9/16	7/8	3.50	7.0	84
5/8	1	3.50	7.0	86
3/4	1 1/16	3.50	7.0	85
7/8	1 1/8	3.75	7.5	86
1	1 1/4	3.87	7.7	84

A few examples of calculations for efficiency will be given, taking the three forms of riveted joints in most common use. The following notation will be used throughout:

T.S. = Tensile strength of plate per square inch.
T = Thickness of plate.
C = Crushing resistance of plate and rivets.
A = Sectional area of rivets.
S = Shearing strength of rivets.
D = Diameter of hole (also diameter of rivets when driven).
P = Pitch of rivets.

In the calculations that follow T.S. will be assumed to be 60,000 pounds, S will be taken at 45,000 pounds, and the value of C may be assumed to be 90,000 to 95,000.

Fig. 74 shows a double-riveted lap joint. The style of riveting in this joint is what is known as chain riveting.

In case the rivets are staggered the same rules for calculating the efficiency will hold as with chain riveting, for the reason that with either style of riveting the unit strip of plate has a width equal to the pitch or distance *p*, Fig. 74.

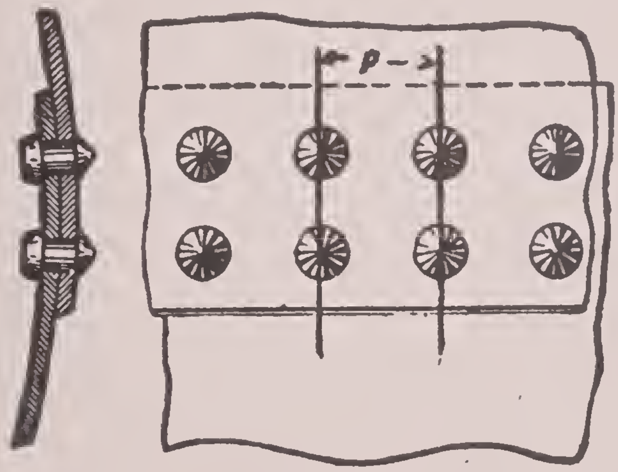


Fig. 74.

The dimensions of the joint under consideration are as follows: P=3¼ in., T=7-16 in.; D=1 in. (which is also diameter of driven rivet).

The strength of the unit strip of solid plate is P×T×T. S.=85,312.

The strength of net section of plate after drilling is P—D×T×T.S.=59,062.

The shearing resistance of two rivets is 2A×S=70,686.

The crushing resistance of rivets and plate is D×2×T×C=78,750.

It thus appears that the weakest part of the joint is the net strip or section of plate, the strength of which is 59,062 and the efficiency $= 59{,}062 \times 100 \div 85{,}312 = 69.2$ per cent.

A double-riveted butt joint is illustrated by Fig. 75, and the dimensions are as follows:

P, inner row of rivets = 2¾ in.
P′, outer row of rivets = 5½ in.
T of plate and butt straps = 7-16 in.
D of hole and driven rivet = 1 in.

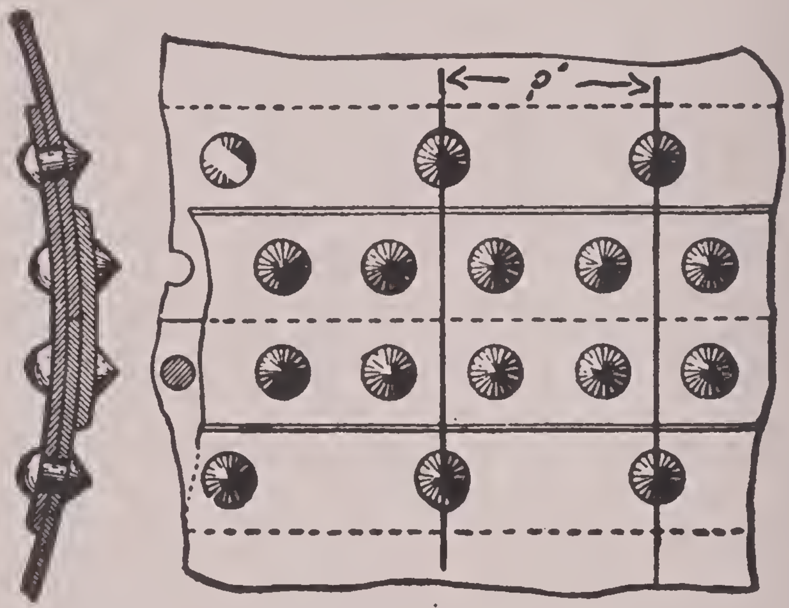


Fig. 75.

Failure may occur in this joint in five distinct ways, which will be taken up in their order.

1. Tearing of the plate at the outer row of rivets. The net strength at this point is $P - D \times T \times T.S.$, which, expressed in plain figures, results as follows: $5.5 - 1 \times .4375 \times 60{,}000 = 118{,}125$.

2. Shearing two rivets in double shear and one in single shear. Should this occur, the two rivets in the inner row would be sheared on both sides of the plate, thus being

in double shear. Opposed to this strain there are four sections of rivets, two for each rivet. Then at the outer row of rivets in the unit strip there is the area of one rivet in single shear to be added. The total resistance, therefore, is $5A \times S$ as follows: $.7854 \times 5 \times 45{,}000 = 176{,}715$.

3. The plate may tear at the inner row of rivets and shear one rivet in the outer row. The resistance in this case would be $P' - 2D \times T \times T.S. + A \times S$ as follows: $5.5 - 2 \times .4375 \times 60{,}000 + .7854 \times 45{,}000 = 127{,}218$.

4. Failure may occur by crushing in front of three rivets. Opposed to this is $3D \times T \times C$, or $1 \times 3 \times .4375 \times 95{,}000 = 124{,}687$.

5. Failure may occur by crushing in front of two rivets and shearing one. The resistance is represented by $2D \times T \times C + 1A \times S$; expressed in figures, $1 \times 2 \times .4375 \times 95{,}000 + .7854 \times 45{,}000 = 118{,}468$.

The strength of a solid strip of plate 5½ in. wide before drilling is $P' \times T \times T.S.$, or $5.5 \times .4375 \times 60{,}000 = 144{,}375$, and the efficiency of the joint is $118{,}125 \times 100 \div 144{,}375 = 81.1$ per cent.

A triple-riveted butt joint is shown in Fig. 76, the dimensions of which are as follows:

$T = 7\text{-}16$ in.
$D = 15\text{-}16$ in.
$A = .69$ in.
$P = 3\tfrac{3}{8}$ in.
$P' = 6\tfrac{3}{4}$ in.

Failure may occur in this joint in either one of five ways.

1. By tearing the plate at the outer row of rivets, where the pitch is 6¾ in. The net strength of the unit strip at this point is $P' - D \times T \times T.S.$, found as follows: $6.75 - .9375 \times .4375 \times 60{,}000 = 152{,}578$.

2. By shearing four rivets in double shear and one in single shear. In this instance, of four rivets in double shear, each one presents two sections, and the one in single shear presents one, thus making a total of nine sections of rivets to be sheared, and the strength is $9A \times S$, or $.69 \times 9 \times 45{,}000 = 279{,}450$.

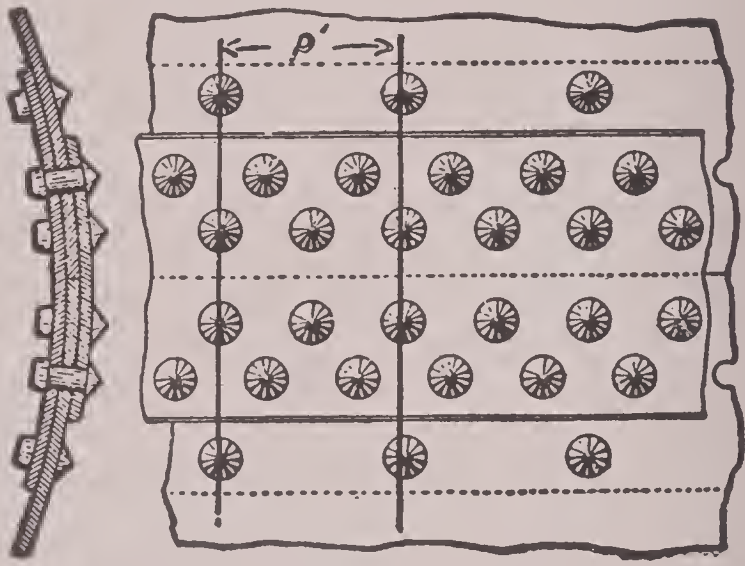


Fig. 76.

3. Rupture of the plate at the middle row of rivets and shearing one rivet. Opposed to this strain the strength is $P' - 2D \times T \times T.S. + 1A \times S$, equivalent to $6.75 - (.9375 \times 2) \times .4375 \times 60{,}000 + .69 \times 90{,}000 = 190{,}068$.

4. Crushing in front of four rivets and shearing one rivet. The resistance in this instance is $4D \times T \times C + 1A \times S$, or $.9375 \times 4 \times .4375 \times 90{,}000 + .69 \times 45{,}000 = 178{,}706$.

5. Failure may be caused by crushing in front of five rivets, four of which pass through both the inside and outside butt straps, while the fifth rivet passes through the inside strap only, and the resistance is 5D × T × C, equivalent to .9375 × 5 × 90,000 = 184,570.

The strength of the unit strip of plate before drilling is P′ × T × T.S., or 6.75 × .4375 × 60,000 = 177,187, and the efficiency is 152,578 × 100 ÷ 177,187 = 86 per cent.

With the constantly increasing demand for higher steam pressures, the necessity for higher efficiencies in the riveted joints of boilers becomes more apparent, and of late years quadruple and even quintuple-riveted butt joints have in many instances come into use. The quadruple butt joint when properly designed shows a high efficiency, in some cases as high as 94.6 per cent. Fig. 77 illustrates a joint of this kind, and the dimensions are as follows:

T = ½in.
D = 15-16 in.
A = .69 in.
P, inner rows = 3¾ in.
P′, 1st outer row = 7½ in.
P″, 2d outer row = 15 in.

The two inner rows of rivets extend through the main plate and both the inside and outside cover plates or butt straps.

The two outer rows reach through the main plate and inside cover plate only, the first outer row having twice the pitch of the inner rows, and the second outer row has twice the pitch of the first.

Taking a strip or section of plate 15 in. wide (pitch of outer row), there are four ways in which this joint may fail.

1. By tearing of the plate at the outer row of rivets. The resistance is P″ — D × T × T.S., or 15 — .9375 × .5 × 60,000 = 421,875.

2. By shearing eight rivets in double shear and three in single shear. The strength in resistance is 19A × S, or .69 × 19 × 45,000 = 589,950.

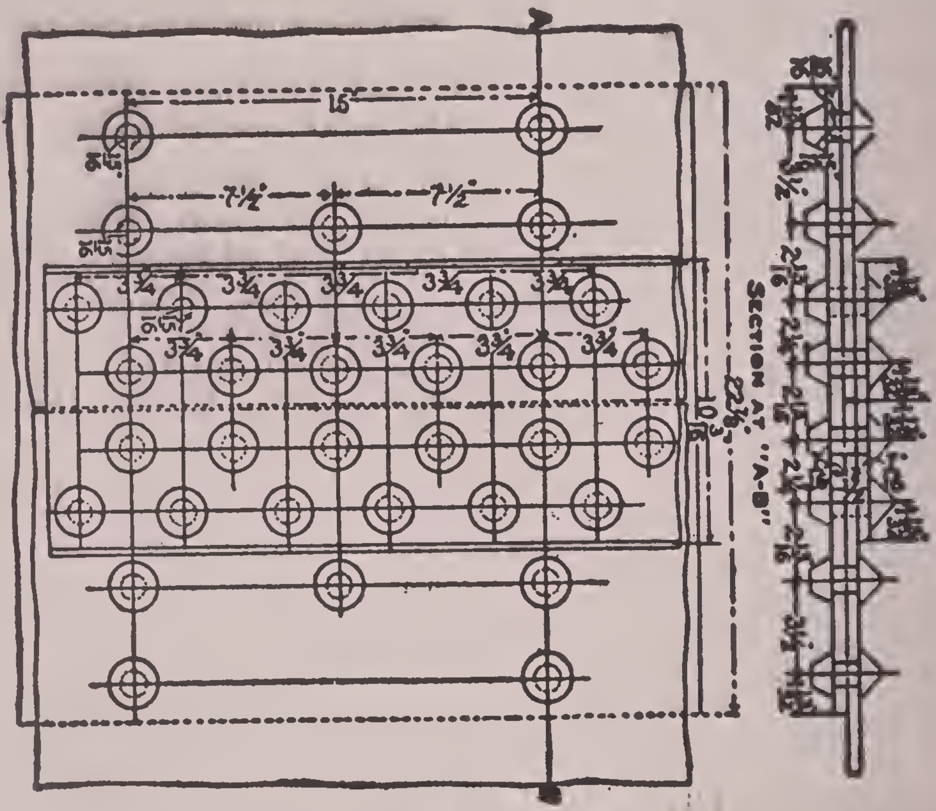


Fig. 77.

3. By tearing at inner rows of rivets and shearing three rivets. The resistance is P″ — 4D × T × T.S. + 3A S, or 15 — (.9375 × 4) × .5 × 60,000 + .69 × 3 45,000 = 430,650.

4. By tearing at the first outer row of rivets, where the pitch is 7½ in., and shearing one rivet. The resist-

ance is P″ — 2D × T × T.S. + A × S, or 15 — (.9375 × 2) × .5 × 60,000 + .69 × 45,000 = 424,800.

It appears that the weakest part of the joint is at the outer row of rivets, where the net strength is 421,875. The strength of the solid strip of plate 15 in. wide before drilling is P″ × T × T.S., or 15 × .5 × 60,000 = 450,000, and the efficiency is 421,875 × 100 ÷ 450,000 = 93.7 per cent.

STAYING FLAT SURFACES. The proper staying or bracing of all flat surfaces in steam boilers is a highly important problem, and while there are various methods of bracing resorted to, still, as Dr. Peabody says, "the staying of a flat surface consists essentially in holding it against pressure at a series of isolated points which are arranged in regular or symmetrical pattern." The cylindrical shell of a boiler does not need bracing, for the very simple reason that the internal pressure tends to keep it cylindrical. On the contrary, the internal pressure has a constant tendency to bulge out the flat surface. Rule 2, Section 6, of the rules of the U. S. Supervising Inspectors provides as follows: "No braces or stays hereafter to be employed in the construction of boilers shall be allowed a greater strain than 6,000 lbs. per square inch of section."

The weakest portion of the crow foot brace when in position is at the foot end, where it is connected to the head by two rivets. With a correctly designed brace the pull on these rivets is direct and the tensile strength of the material needs to be considered only, but if the form of the brace is such as to bring the rivet holes above or below the center line of the brace, or if the rivets are pitched too far from the body of the brace, there will be a certain leverage exerted upon the rivets in addition to the direct pull. Fig. 78 shows a brace of incorrect design and Figs. 79 and 80 show braces designed along correct lines.

The problem of properly staying the flat crown sheet of a horizontal fire-box boiler, especially a locomotive boiler, is a very difficult one and has taxed the inventive genius of some of the most eminent engineers.

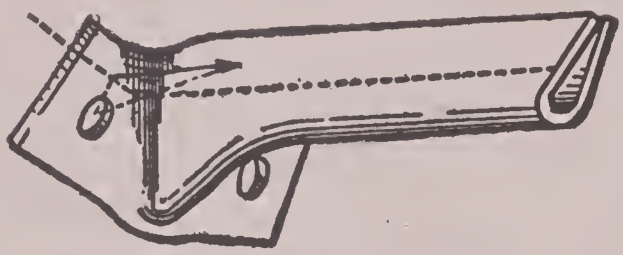


Fig. 78.

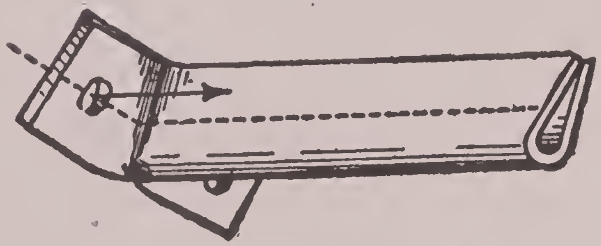


Fig. 79.

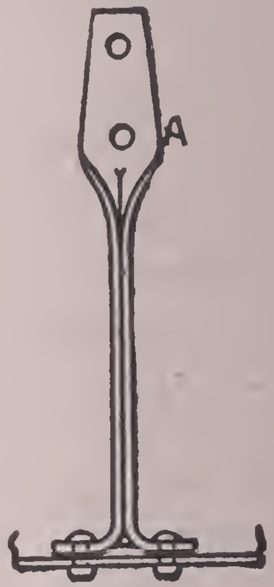


Fig. 80.

For simplicity of construction and great strength the cylindrical form of fire-box known as the Morison corrugated furnace has proved to be very successful. This form of fire-box was in 1899 applied to a locomotive by Mr. Cornelius Vanderbilt, at the time assistant superintendent of motive power of the New York Central and Hudson River R. R. This furnace was rolled of ¾-in. steel, is 59 in. internal diameter and 11 ft. 2¼ in. in length. It was tested under an external pressure of 500 lbs. per square inch before being placed in the boiler. It is carried at the front end by a row of radial sling stays from the outside plate, and supported at the rear by the back head. Figs. 81 and 82 show respectively a sectional

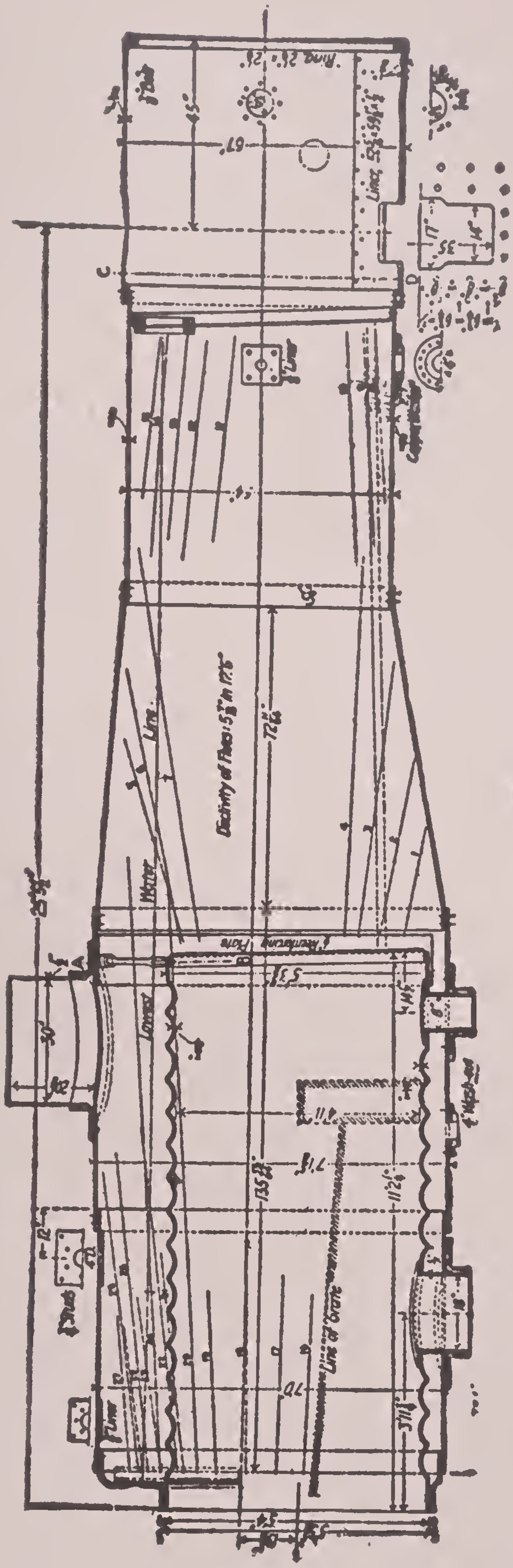
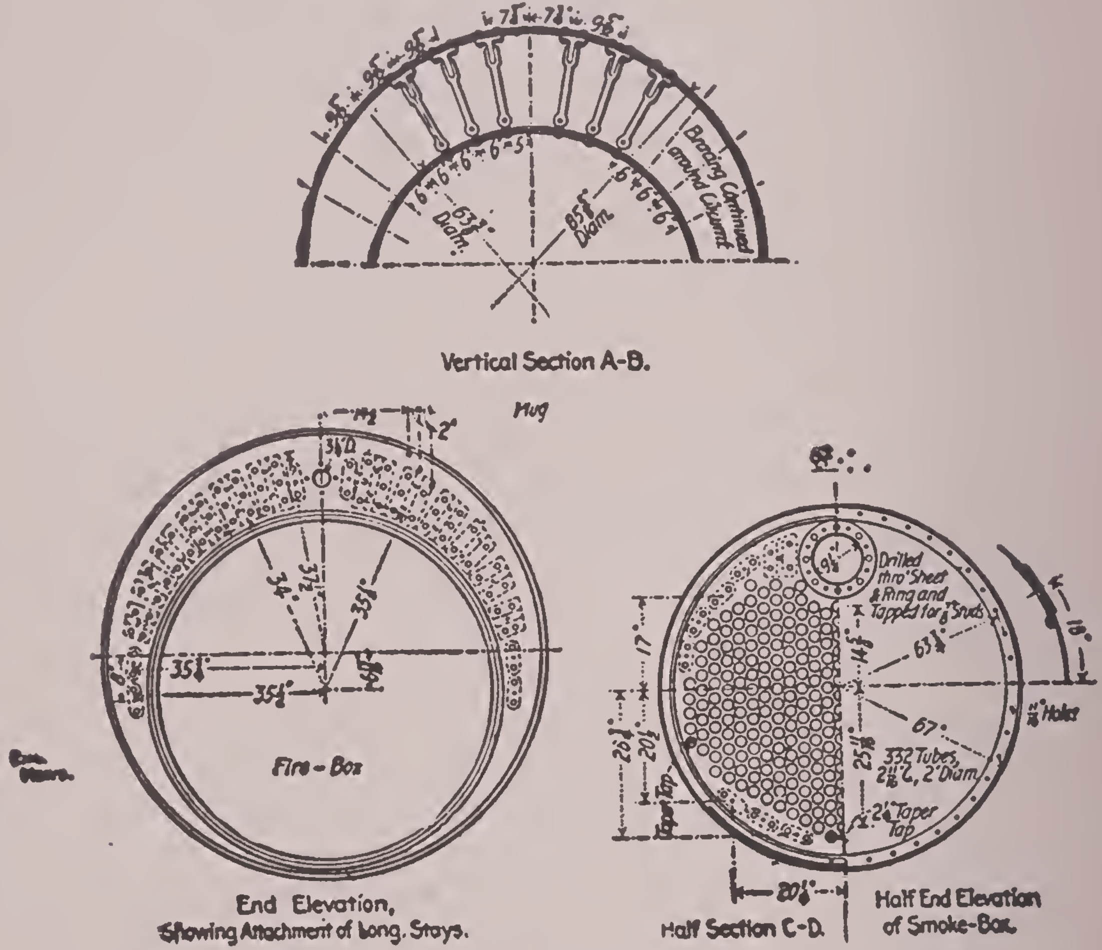

Water
Line
Lowest
Reinforcing Plate
Line of Grate
Flues
72¾"
135⅞"
30"
6" Washout

Fig. 81.

view and an end elevation of this boiler. It will be seen at once that the question of stays for a fire-box of this type becomes very simple.

Calculating the Strength of Stayed Surfaces. In calculations for ascertaining the strength of stayed surfaces, or for finding the number of stays required for


Bracing Continued around Circumf.
Diam.
Fire-Box
Drilled thro' Sheet & Ring and Tapped for $\frac{7}{8}$" Studs
332 Tubes, $2\frac{11}{16}$" C., 2" Diam.
$2\frac{1}{4}$" Taper Tap
Taper Tap
$\frac{7}{8}$" Holes
67"
$63\frac{1}{2}$"
$80\frac{1}{2}$"
17"
18"

Vertical Section A-B.

End Elevation, Showing Attachment of long. Stays.

Half Section C-D.

Half End Elevation of Smoke-Box.

Fig. 82.

any given flat surface in a boiler, the working pressure being known, it must be remembered that each stay is subjected to the pressure on an area bounded by lines drawn midway between it and its neighbors. Therefore the area in square inches, of the surface to be supported by each stay, equals the square of the pitch or distance in inches between centers of the points of connection of the stays to the flat plate. Thus, suppose the stays in a certain boiler are spaced 8 in. apart, the area sustained by each stay = 8 × 8 = 64 sq. in., or assume the stay bolts in a locomotive fire-box to be pitched 4½ in. each way, the area supported by each stay bolt = 4½ × 4½ = 20¼ sq. in.

The minimum factor of safety for stays, stay bolts and braces is 8, and this factor should enter into all computations of the strength of stayed surfaces.

The pitch for stays depends upon the thickness of the plate to be supported, and the maximum pressure to be carried.

In computing the total area of the stayed surface it is safe to assume that the flange of the plate, where it is riveted to the shell, sufficiently strengthens the plate for a distance of 2 in. from the shell, also that the tubes act as stays for a space of 2 in. above the top row. Therefore the area of that portion of the flat head or plate bounded by an imaginary line drawn at a distance of 2 in. from the shell and the same distance from the last row of tubes is the area to be stayed. This surface may be in the form of a segment of a circle, as with a cylindrical boiler, or it may be rectangular in shape, as in the case of a locomotive or other fire-box boiler. Other forms of stayed surfaces are often encountered, but in general the rules applicable to segments or rectangular figures will suffice for ascertaining the areas.

By the use of Table 13 and the rule that follows, the area of the segmental portion of any boiler head may be ascertained.

TABLE 13

AREAS OF SEGMENTS OF A CIRCLE

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.2	.11182	.243	.14751	.286	.18542	.329	.22509
.201	.11262	.244	.14837	.287	.18633	.33	.22603
.202	.11343	.245	.14923	.288	.18723	.331	.22697
.203	.11423	.246	.15009	.289	.18814	.332	.22792
.204	.11504	.247	.15095	.29	.18905	.333	.22886
.205	.11584	.248	.15182	.291	.18996	.334	.22980
.206	.11665	.249	.15268	.292	.19086	.335	.23074
.207	.11746	.25	.15355	.293	.19177	.336	.23169
.208	.11827	.251	.15441	.294	.19268	.337	.23263
.209	.11908	.252	.15528	.295	.19360	.338	.23358
.21	.11990	.253	.15615	.296	.19451	.339	.23453
.211	.12071	.254	.15702	.297	.19542	.34	.23547
.212	.12153	.255	.15789	.298	.19634	.341	.23642
.213	.12235	.256	.15876	.299	.19725	.342	.23737
.214	.12317	.257	.15964	.3	.19817	.343	.23832
.215	.12399	.258	.16051	.301	.19908	.344	.23927
.216	.12481	.259	.16139	.302	.20000	.345	.24022
.217	.12563	.26	.16226	.303	.20092	.346	.24117
.218	.12646	.261	.16314	.304	.20184	.347	.24212
.219	.12729	.262	.16402	.305	.20276	.348	.24307
.22	.12811	.263	.16490	.306	.20368	.349	.24403
.221	.12894	.264	.16578	.307	.20460	.35	.24498
.222	.12977	.265	.16666	.308	.20553	.351	.24593
.223	.13060	.266	.16755	.309	.20645	.352	.24689
.224	.13144	.267	.16843	.31	.20738	.353	.24784
.225	.13227	.268	.16932	.311	.20830	.354	.24880
.226	.13311	.269	.17020	.312	.20923	.355	.24976
.227	.13395	.27	.17109	.313	.21015	.356	.25071
.228	.13478	.271	.17198	.314	.21108	.357	.25167
.229	.13562	.272	.17287	.315	.21201	.358	.25263
.23	.13646	.273	.17376	.316	.21294	.359	.25359
.231	.13731	.274	.17465	.317	.21387	.36	.25455
.232	.13815	.275	.17554	.318	.21480	.361	.25551
.233	.13900	.276	.17644	.319	.21573	.362	.25647
.234	.13984	.277	.17733	.32	.21667	.363	.25743
.235	.14069	.278	.17823	.321	.21760	.364	.25839
.236	.14154	.279	.17912	.322	.21853	.365	.25936
.237	.14239	.280	.18002	.323	.21947	.366	.26032
.238	.14324	.281	.18092	.324	.22040	.367	.26128
.239	.14409	.282	.18182	.325	.22134	.368	.26225
.24	.14494	.283	.18272	.326	.22228	.369	.26321
.241	14580	.284	.18362	.327	.22322	.37	.26418
.242	.14666	.285	.18452	.328	.22415	.371	.26514

TABLE 13—*Continued*

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.372	.26611	.405	.29827	.438	.33086	.471	.36373
.373	.26708	.406	.29926	.439	.33185	.472	.36471
.374	.26805	.407	.30024	.44	.33284	.473	.36571
.375	.26901	.408	.30122	.441	.33384	.474	.36671
.376	.26998	.409	.30220	.442	.33483	.475	.36771
.377	.27095	.41	.30319	.443	.33582	.476	.26871
.378	.27192	.411	.30417	.444	.33682	.477	.36971
.379	.27289	.412	.30516	.445	.33781	.478	.37071
.38	.27386	.413	.30614	.446	.33880	.479	.37171
.381	.27483	.414	.30712	.447	.33980	.48	.37270
.382	.27580	.415	.30811	.448	.34079	.481	.37370
.383	.27678	.416	.30910	.449	.34179	.482	.37470
.384	.27775	.417	.31008	.45	.34278	.483	.37570
.385	.27872	.418	.31107	.451	.34378	.484	.37670
.386	.27969	.419	.31205	.452	.34477	.485	.37770
.387	.28067	.42	.31304	.453	.34577	.486	.37870
.388	.28164	.421	.31403	.454	.34676	.487	.37970
.389	.28262	.422	.31502	.455	.34776	.488	.38070
.39	.28359	.423	.31600	.456	.34876	.489	.38170
.391	.28457	.424	.31699	.457	.34975	.49	.38270
.392	.28554	.425	.31798	.458	.35075	.491	.38370
.393	.28652	.426	.31897	.459	.35175	.492	.38470
.394	.28750	.427	.31996	.46	.35274	.493	.38570
.395	.28848	.428	.32095	.461	.35374	.494	.38670
.396	.28945	.429	.32194	.462	.35474	.495	.38770
.397	.29043	.43	.32293	.463	.35573	.496	.38870
.398	.29141	.431	.32392	.464	.35673	.497	.38970
.399	.29239	.432	.32941	.465	.35773	.498	.39070
.4	.29337	.433	.32590	.466	.35873	.499	.39170
.401	.29435	.434	.32689	.467	.35972	.5	.39270
.402	.29533	.435	.32788	.468	.36072		
.403	.29631	.436	.32887	.469	.36172		
.404	.29729	.437	.32987	.47	.36272		

Rule. Divide the height of the segment by the diameter of the circle. Then find the decimal opposite this ratio in the column headed "Area." Multiply this area by the square of the diameter. The result is the required area.

Example. Diameter of circle = 72 in. Height of segment = 25 in. 25 ÷ 72 = .347, which will be found in the column headed "Ratio," and the area opposite this .24212. Then .24212 × 72 × 72 = 1,255 sq. in., area of segment.

STRENGTH OF UNSTAYED SURFACES. A simple rule for finding the bursting pressure of unstayed flat surfaces is that of Mr. Nichols, published in the Locomotive, February, 1890, and quoted by Professor Kent in his pocket-book. The rule is as follows: "Multiply the thickness of the plate in inches by ten times the tensile strength of the material used, and divide the product by the area of the head in square inches." Thus:

Diameter of head = 66 in.
Thickness of head = ⅝ in.
Tensile strength = 55,000 lbs.
Area of head = 3,421 sq. in.

⅝ × 55,000 × 10 ÷ 3,421 = 100, which is the number of pounds pressure per square inch under which the unstayed head would bulge.

If we use a factor of safety of 8, the safe working pressure would be 100 ÷ 8 = 12.5 lbs. per square inch, but as the strength of the unstayed head is at best an uncertain quantity it has not been considered in the foregoing calculations for bracing, except as regards that portion of it that is strengthened by the flange.

In all calculations for the strength of stayed surfaces, and especially where diagonal crow foot stays are used, the strength of the rivets connecting the stay to the flat plate must be carefully considered. A large factor of safety, never less than 8, should be used, and the cross section of that portion of the foot of the stay through which the rivet holes are drilled should be large enough, after deducting the diameter of the hole, to equal the sectional area of the body of the stay.

DISHED HEADS. In boiler work where it is possible to use dished, or "bumped up" heads as they are sometimes called, this type of head is rapidly coming into use. Dished heads may be used in the construction of steam drums, also in many cases for dome-covers, thus obviating the necessity of bracing.

As there has been a constantly growing demand for an increase in the power of locomotives, and as the boiler is the source of power, builders have been constrained to change the design of locomotive boilers in such manner as would bring about an enlargement of both the heating surface and the grate area. Consequently the old wagon top type of boiler, with the fire-box down between the drivers and close to the track, has been largely superseded by the modern straight-top boiler having a wide fire-box, which as applied to freight engines with low wheels is usually above the rear drivers, but as applied to passenger engines with high wheels is usually behind the rear drivers and supported by trailing wheels, as in "Atlantic 4-4-2," "Prairie 2-6-2" and the "Pacific 4-6-2" types. The introduction of the wide fire-box and consequent increase of great area has made it possible to burn cheaper grades of coal than was possible with the older type of boiler. It may be used (with some modifications) for both soft and hard coal.

Fig. 83 shows a sectional elevation of a modern locomotive boiler, and Fig. 84 an end view of one-half of the flue sheet and one-half of the back head.

The staying of the heads and crown sheet is clearly

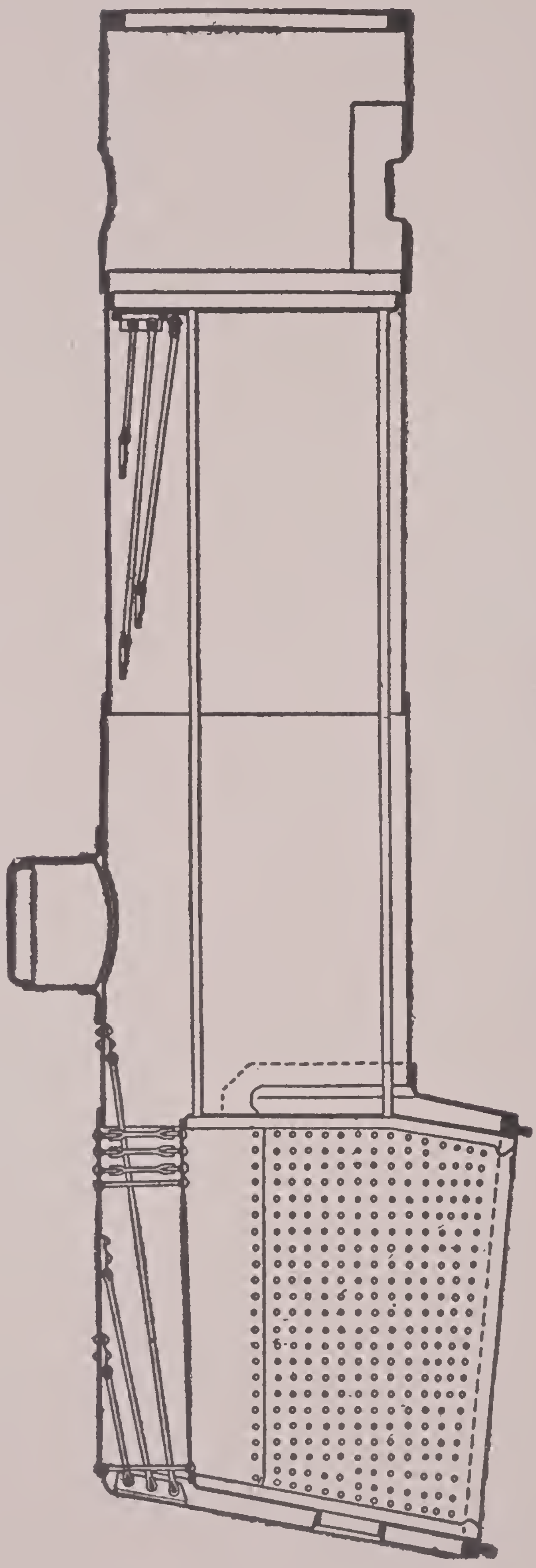


Fig. 83. Section of Modern Boiler.

illustrated. The general dimensions of the fire-box at the present time varies from 8 ft. to 10 ft. 4 in. in length, with a width of from 40 to 42 in., and a depth of 6 to 7 ft. in front, and 5 ft. 6 in. to 6 ft. 6 in. at the back, the size depending upon the type of engine and the kind of work it was designed to perform.

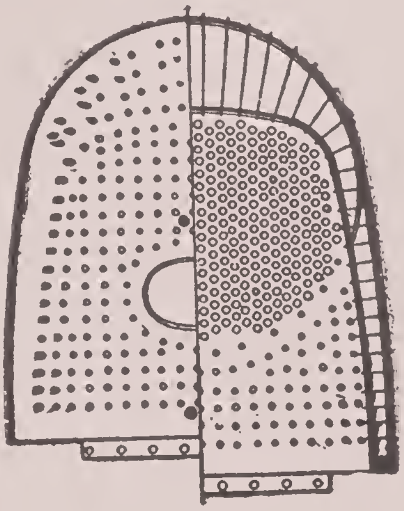


Fig. 84.

The diameter of the barrel or cylindrical portion of locomotive boilers built for train service varies all the way from 60 to 78 in., and some recent splendid examples of the locomotive builders' art have boilers 83 in. in diameter.

QUESTIONS

164. What are the four vital organs of a locomotive boiler?
165. Describe the mud ring.
166. Describe in general terms the fire-box.
167. How are the sides of the fire-box stayed?
168. Describe a stay bolt.

169. How far apart, center to center, are stay bolts usually spaced?

170. What causes stay bolts to break?

171. Why are stay bolts made hollow?

172. Describe the flexible stay bolt.

173. What advantage has a flexible stay bolt over a rigid one?

174. Is it necessary to strengthen the crown sheet by stays?

175. Why does the crown sheet need to be supported?

176. Name the three methods usually employed for staying the crown sheet.

177. Describe crown bars, and how applied.

178. Why is there a space preserved between the crown bars and top of crown sheet?

179. How are the crown bolts attached?

180. Why are thimbles placed between the crown bars and top of crown sheet?

181. Describe the radial system of staying the crown sheet.

182. What is the principal defect in this system?

183. Describe the Belpaire system.

184. What great advantage has this form of fire-box over others?

185. Why are crown sheets usually made to slope downwards from the front to the back end?

186. How are the heads of the boiler usually stayed?

187. What are diagonal crow foot stays?

188. How is the flue sheet braced?

189. What is a gusset stay, and how is it connected to the head and shell?

190. Why should the flue sheet be thicker than the shell?

191. What advantage is there in setting the tubes in vertical rows?

192. What is the usual diameter of locomotive tubes?

193. How are the tubes made water-tight in the sheet?

194. Describe the Prosser tube expander and method of using it.

195. Describe the Dudgeon roller expander.

196. How is it used?

197. What is meant by the expression tensile strength of a boiler sheet?

198. What is the usual tensile strength of steel boiler plate?

199. What should be the tensile strength of the rods from which rivets are made?

200. What is the shearing resistance of iron rivets?

201. What is the shearing resistance of steel rivets?

202. What is meant by the efficiency of a riveted joint?

203. What type of joint should be used for plates ½ in. thick or more?

204. Give the diameter of rivet, pitch, and efficiency of a double-riveted joint.

205. What is the usual efficiency of single-riveted joints?

206. How should double-riveted joints be designed in order to obtain the highest efficiency?

207. Describe a triple-riveted butt joint.

208. How should a triple-riveted butt joint be designed in order to obtain the highest efficiency?

209. What is meant by the expression, the unit strip or net section of plate, as used in calculating the efficiency of a riveted joint?

210. What is the usual efficiency of the triple-riveted butt joint?

211. What efficiency per cent does the quadruple-riveted butt joint show when properly designed?

212. Why is it that the cylindrical portion of a boiler does not require to be stayed?

213. What effect does the pressure inside a boiler have upon flat surfaces, such as the heads, crown sheet, etc.?

214. Where is the weakest portion of a crow foot brace?

215. How is the area in square inches to be supported by each stay, ascertained?

216. What is the minimum safety factor for stays and stay bolts?

217. What two factors govern the pitch for stays?

218. What portions of the heads do not need to be braced?

219. Is it possible to weld boiler seams?

220. Describe in general terms the modern locomotive boiler.

221. What are the general dimensions of the fire-box?

THROTTLE AND DRY PIPE.

Having studied at some length the construction of the boiler and the generation of steam, it is now in order to examine into the method by which the steam is conveyed to the cylinders of the engine, where it, or rather the heat that it contains, performs its work. The main factors in the transmission of the steam from the boiler to the interior of the cylinders, and from there to the open air, are the throttle valve and pipe, the dry pipe, the steam pipes and passages, the valves and ports, the exhaust passages and ports, and the exhaust nozzles. These will each be described in regular order, with the exception of the valves and ports, which will be fully described in the chapters on valves and valve setting.

The steam dome O, Fig. 55, is a cylindrical chamber made of boiler plate and riveted to the top of the boiler, usually directly over the fire-box. The function of the dome is to serve as a steam chamber that is elevated as high as possible above the surface of the water in the boiler, in order that the steam supplied to the cylinders, all of which is drawn from this chamber, may be as dry as it is possible to have it.

The steam is conducted from the dome to the cylinders through the dry pipe P-Q-R, Fig. 55, which extends from the top of the dome to the front flue sheet or head of the boiler. Connected to the front end of the dry pipe, inside the smoke box, are two cast iron curved pipes 1-2, Fig. 85, called the steam pipes, which conduct the steam to the steam chests, or valve chests as they are sometimes called. The horizontal portion of the dry pipe

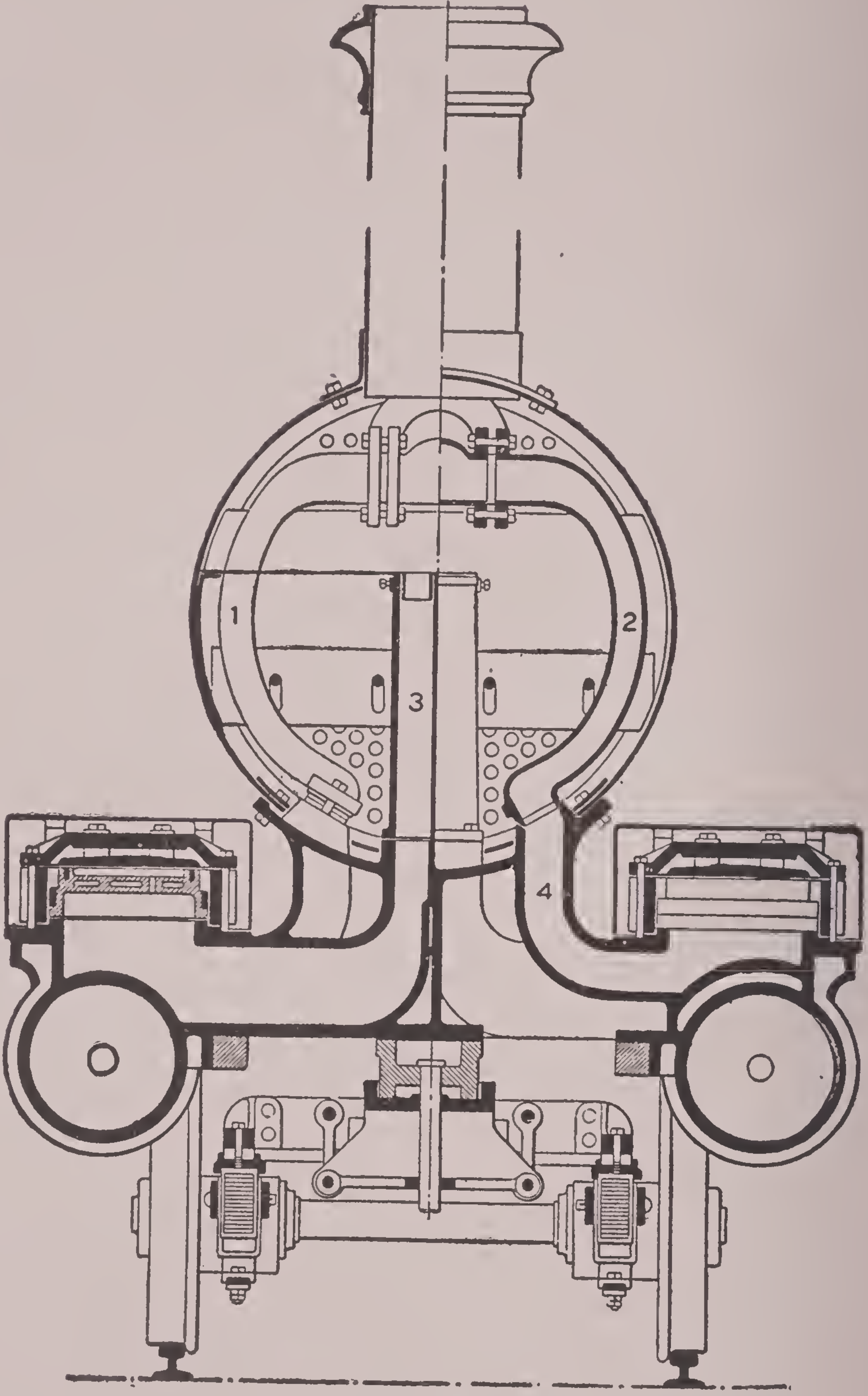


Fig. 85.

extending through the boiler is made of wrought iron, and the vertical portion T, Fig. 55, called the throttle pipe, and which is within the dome, is made of cast iron. At the top of this pipe, near the top of the dome, the throttle U, Fig. 55, for controlling the steam, is usually located, although not always, as it is sometimes placed in the smoke box at the front end R of the dry pipe.

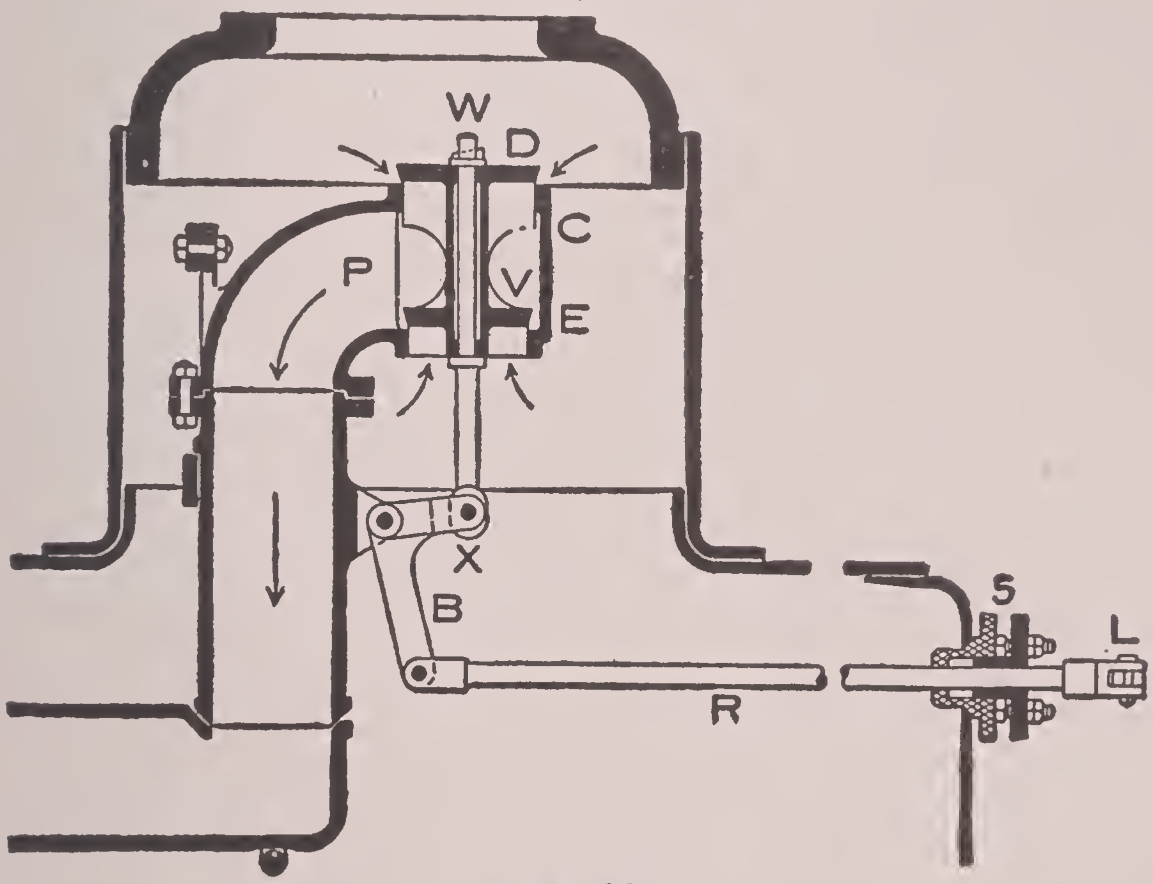


Fig. 86.

Formerly the throttle valve was a plain slide valve that moved upon a seat in which were ports similar in form to the steam ports in the valve chests, but smaller in size. The principal objection to this type of throttle valve for a locomotive was that the pressure of the steam upon it when closed made it very difficult to open the throttle gradually, or to regulate or adjust it while open —two very important points in the operation of a locomotive. A much better form of throttle has been largely adopted in late years. This valve is shown at U, Fig. 55, and on a larger scale by Figs. 86 and 87, which give a sectional view and a plan of the throttle pipe, valve, and throttle lever.

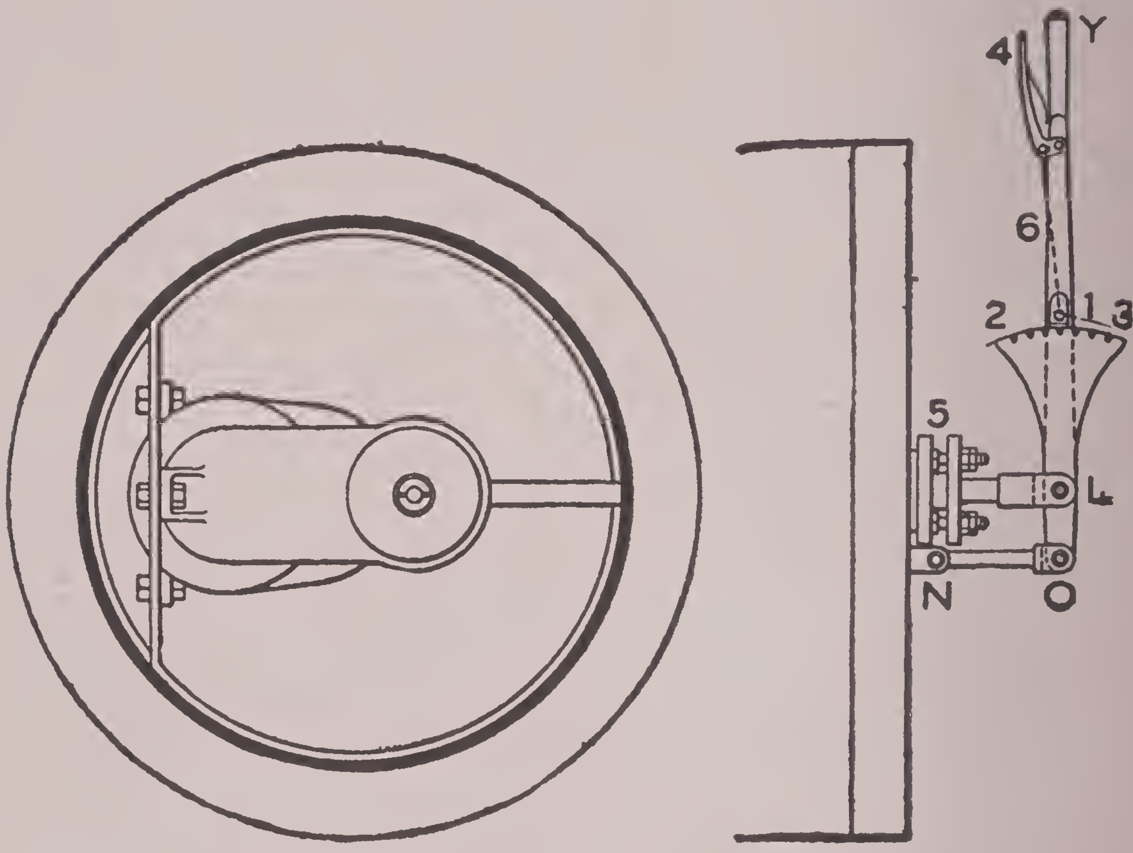


Fig. 87.

The valve V, Fig. 86, is a double poppet valve, having two circular disks D and E, which cover two corresponding openings in the case C on the end of the pipe P. When the valve is raised and the disks are off their seats the steam flows in around their edges, as shown by the arrows. The disks are not the same diameter, the top one being slightly larger. The steam pressure in the boiler acts upon the top of disk D and upon the bottom of disk E. If the two disks were exactly the same in diameter the valve would be balanced, but this is not desirable, as there might thus be a possibility of its being opened accidentally after the engineer had closed it. There is also another reason why the lower disk must be smaller in diameter than the upper one, viz., that it may be introduced through the top opening of the casing C, so as to cover the lower opening. There is thus a slightly greater pressure on the top surface of the upper disk tending to keep the valve closed, than there is on the bottom surface of the lower disk tending to raise the valve and open it. This arrangement of the parts causes the throttle to stay in any position it may be placed, while at the same time it moves comparatively easily. The means whereby the throttle is opened and closed are also shown in Figs. 86 and 87.

The stem W-X of the valve V extends downwards and connects with the upper arm of the bell crank B, Fig. 86. Connected to the lower arm of this bell crank, and extending through the back boiler head into the cab, is a rod R, called the throttle stem. This rod passes through a steam-tight stuffing box in the boiler head. The throttle lever Y, Fig. 87, is connected to the throttle stem at L and attached to a link N-O at O. This link is connected to the boiler head by a stud and pin at N, Fig. 87. The link is free to vibrate slightly, which enables the connection at L to move in a straight line. This provision causes the stem R, Fig. 86, to also move in a straight line in the stuffing box 5, which is very necessary in order that it may be kept steam-tight. Referring to Fig. 87, which is a plan view, the throttle lever Y is fitted with a latch 1 that gears into the curved rack 2-3, in order to hold the throttle in any required position. The latch 1 is operated by a trigger 4, connected by the rod.

The steam, being admitted by the throttle valve V into the throttle pipe P, passes on into the dry pipe P-Q-R, Fig. 55. This pipe, after passing through the front flue sheet of the boiler, is fitted with a T-pipe, thus dividing it into two branches to which the steam pipes are connected. These connections, which are all within the smoke-box, are clearly illustrated in Fig. 85, to which reference is now made.

The steam pipes 1 and 2 are connected to each of the two branches of the T-pipe at their top ends and to the cylinder castings at their bottom ends. The steam is thus conducted to the valve chests. Fig. 85 shows a sectional view of one of the steam pipes, 2 on the right and a section of one of the exhaust pipes 3 on the left. The steam pipes are exposed to great changes of temperature as a result of their being within the smokebox and to which they are subjected, making it very difficult to keep the joints tight.

Another difficulty is also generally encountered in the assembling of the various parts forming these connections, as, for instance, if the upper end of pipe 4 in the cylinder casting, Fig. 85, were either too near or too far from the center line of the engine it would be necessary to move the end of pipe 2, either to the right or to the left, in order to bring it in line for connecting to 4. It is therefore necessary that there be a certain degree of flexibility in these connections, and this is accomplished by the use of ball joints. Fig. 88 illustrates a ball joint. The end of one of the pipes is turned into the form of a sphere or globe, and the end of the other pipe is formed into a corresponding concave shape, as shown in Fig. 88. This form of joint permits a lateral movement in either direction of the lower end of pipe 2 to bring it in line with the upper end of pipe 4.

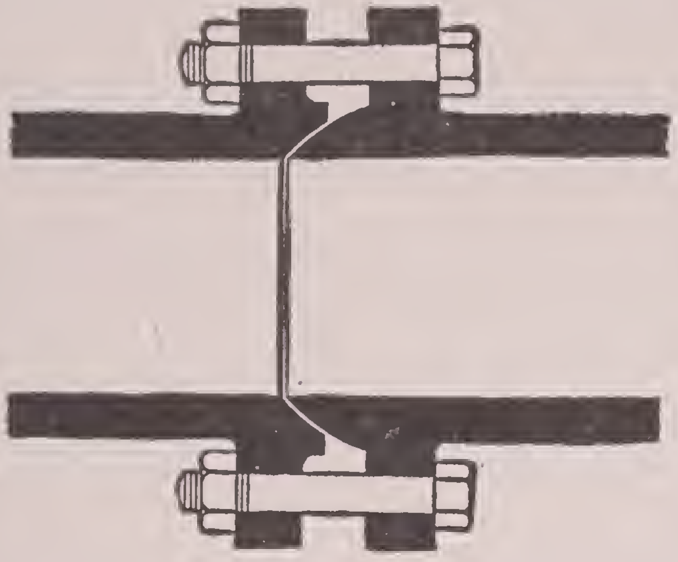


Fig. 88.

Another and still better form of flexible joint is illustrated in Fig. 89. In this joint a ring is interposed between the ends of the pipes. One side of this ring is spherical and the other side is flat, the ends of the pipes

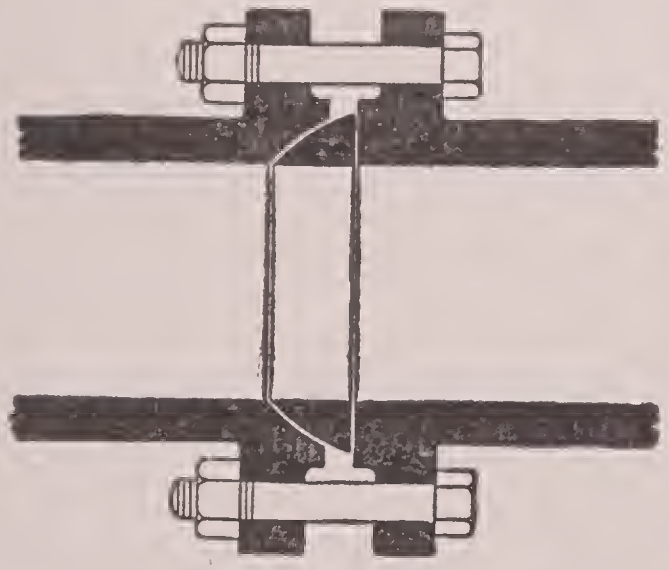


Fig. 89.

being shaped to correspond. With this form of joint the pipes are slightly adjustable in every direction, and the joints accommodate themselves to any and all motion that may be caused by expansion and contraction.

In order that the student may be able to clearly understand the route taken by the steam in its passage from the boiler to the cylinders and thence to the smoke stack, the following clear exposition of this subject, together with the illustrations (Figs. 90, 91 and 92), is here reproduced from an article by Mr. W. G. Wallace, published in the January issue of the Locomotive Firemen's Magazine:

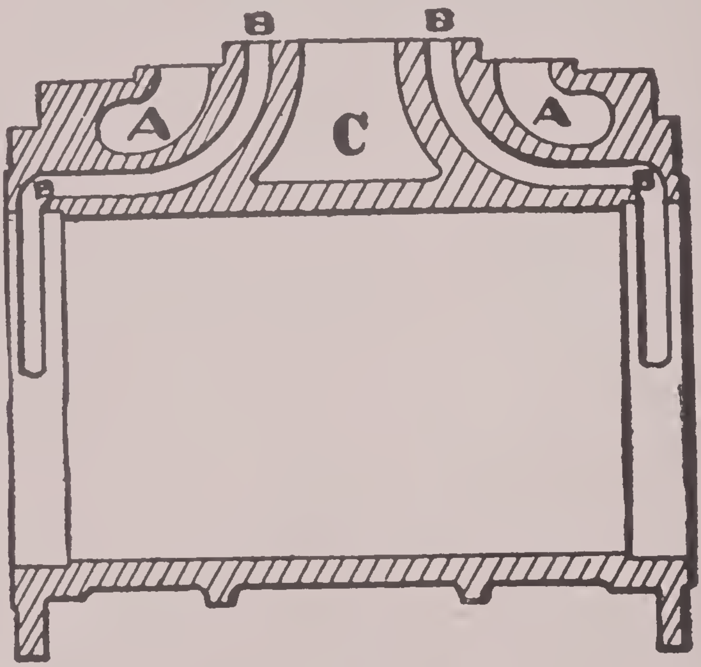


Fig. 90. Longitudinal Sectional View of Cylinder.

"Steam is generated at or near the heating surfaces of the boiler and rises into the dome. When the throttle valve is open steam enters the stand pipe, and follows, through it, to the dry pipe to the "nigger head," or tee, in the smokebox. It then enters the steam pipes and is conducted to the cylinder saddle, thence through the passage *A A* (see illustration) to the steam chest. If the valve is now in the center of its seat it can go no farther, but when the port is uncovered by the valve, steam is admitted to the end of the cylinder nearest the opened admission port, shown at *B B,* and exerts a pressure on the piston nearly equal to that of the steam chest pressure while the port is open. This pressure is exerted on the piston and transmitted to the piston rod and connecting rod to the crank pin, and produces a rotative effect on the wheel in proportion to the pressure and the position of the crank pin above or below a line drawn through the center of the main driving axle and cylinder. If the steam is cut off before the piston has reached the end of its stroke, the valve having closed the port, the steam confined in the cylinder forces the piston to the completion of its stroke by its expansive force acting like a

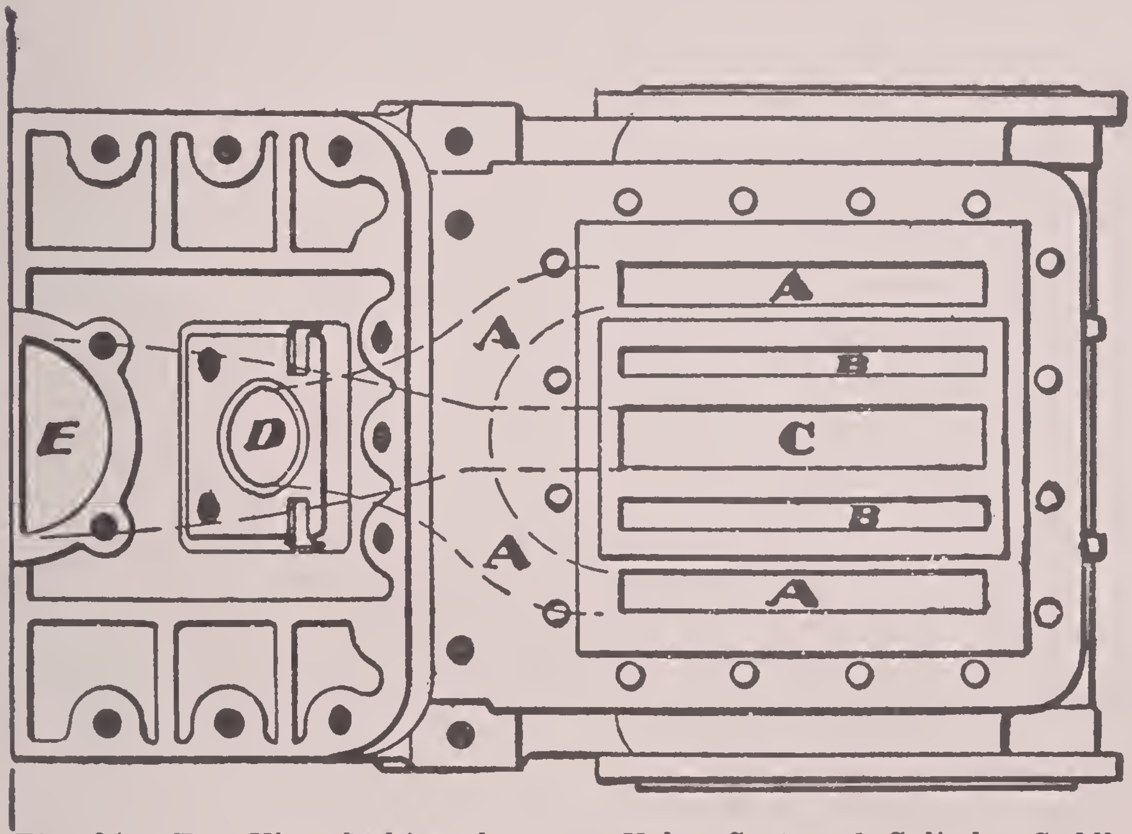


Fig. 91. Top View looking down on Valve Seat and Cylinder Saddle.

spring. This is the expansion of the steam in the cylinder. Now, the valve having traveled far enough forward, the steam is admitted to the other end of the cylinder and forces the piston forward, and the exhaust cavity in the valve extends from the admission port to the exhaust port in the valve seat, to allow the exhaust steam, or the steam that has pushed the piston back, to escape through the admission port which it entered, pass under the valve, over the bridge, and into the exhaust passage *C*, through the cylinder saddle again, into the exhaust

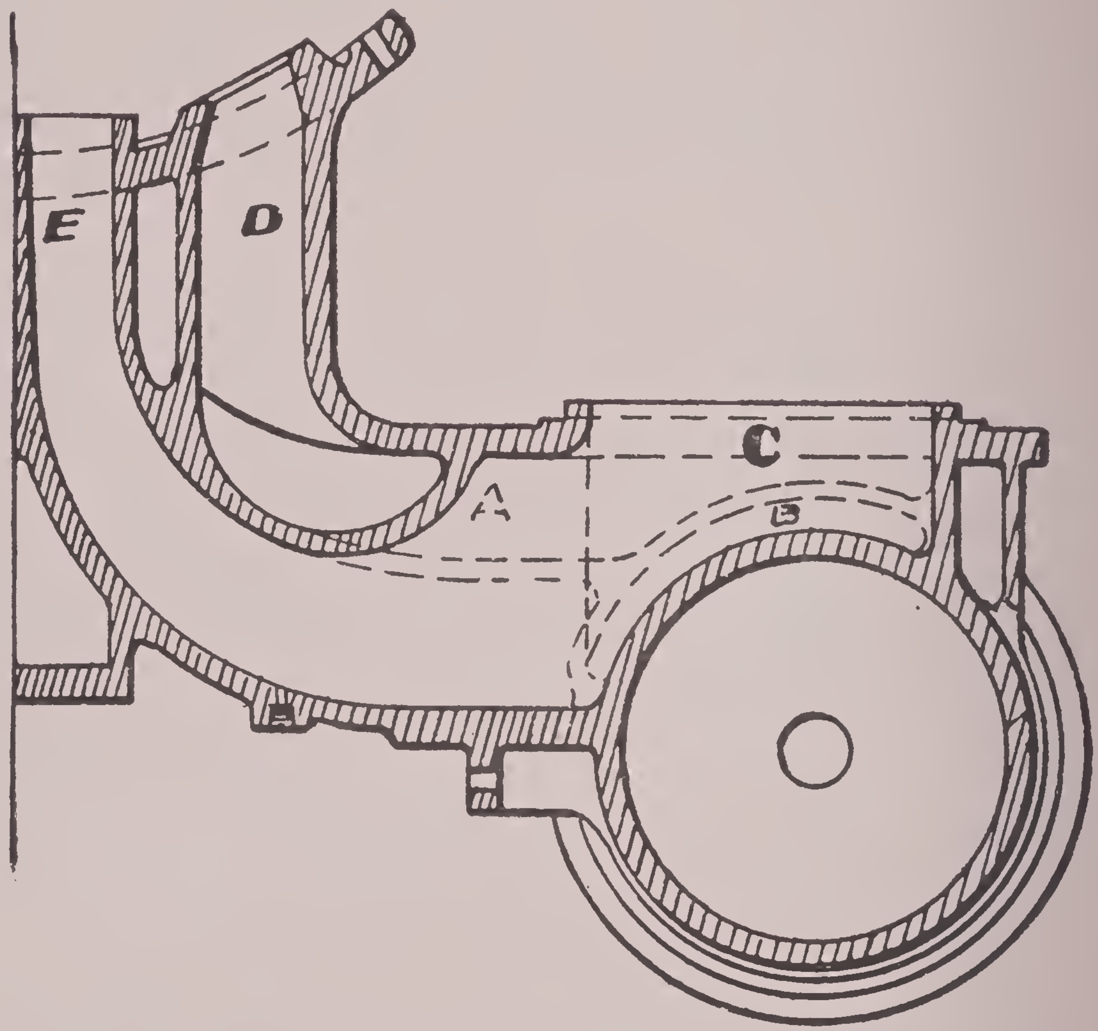


Fig. 92. Cross Sectional View of Cylinder and Saddle, showing Construction.

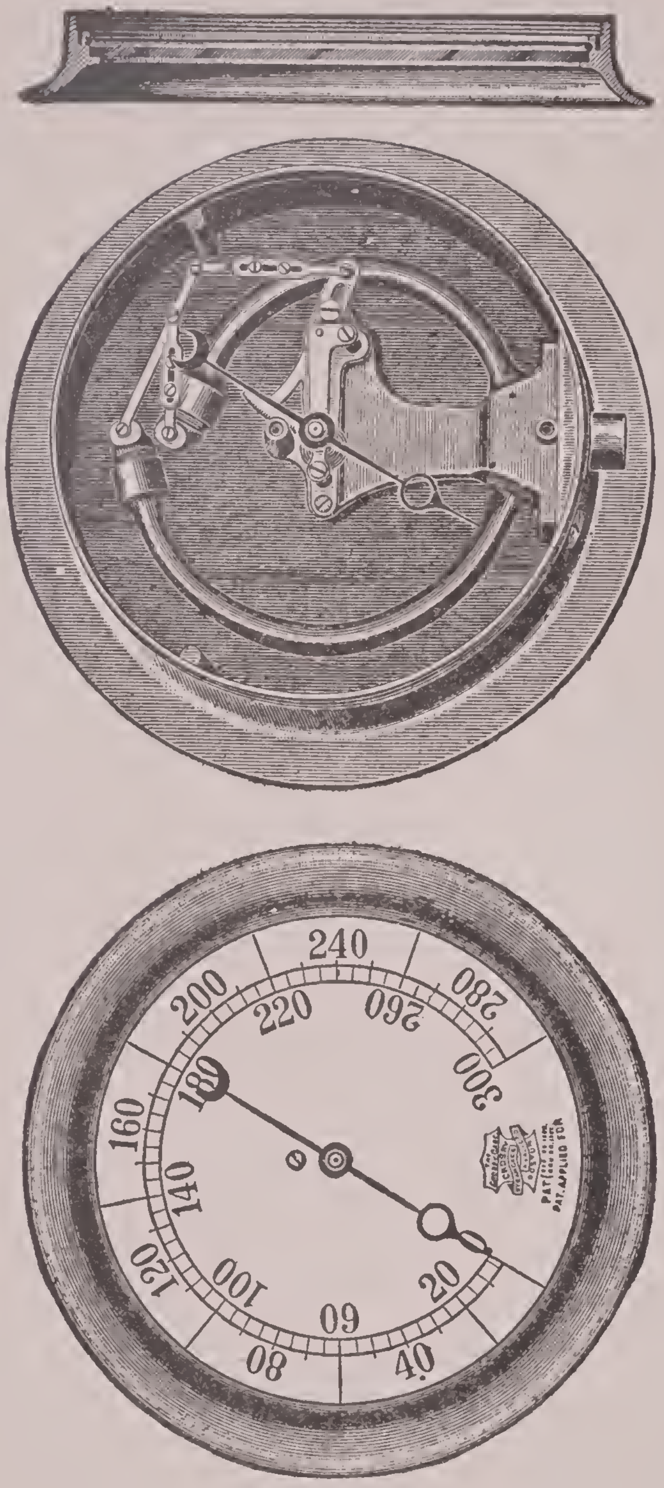
pipe and out through the nozzle tip, through the petticoat or draft pipe and out of the stack.

"There are usually five openings in the cylinder saddle to the steam chest, as shown in the illustrations. Fig. 90 shows a sectional view if the cylinder was cut in two and lengthwise through its center. Fig. 91 is a view looking down on the valve seat and cylinder saddle. Fig. 92 is an end view showing its construction, and the dotted lines represent lines that cannot be seen. Ports *A A* are to admit steam to the steam chest when the throttle is open. Ports B, B, and C exhaust the steam from the cylinder when the exhaust cavity of the valve extends over the bridge ports B and C.

"Opening D in the cylinder saddle is to connect with the steam pipes to the steam passage for the purpose of supplying steam to the steam chest, and opening E is to allow the steam to escape from the cylinder through ports B and C to the exhaust."

STEAM GAUGES AND POP VALVES.

As the steam gauge is an instrument that is particularly interesting to the fireman, it is fitting that a short description of it be inserted here. There are different types of steam gauges in use, but the one most commonly used, and which no doubt is the most reliable, is known as the Bourdon spring gauge. This gauge consists of a thin, curved, flattened metallic tube, closed at both ends and connected to the steam space of the boiler by a small pipe, bent at some portion of its length into a curve or circle that becomes filled with water of condensation, and thus prevents the hot live steam from coming



Sectional View.

Fig. 93. Crosby Locomotive Pressure Gauge.

directly in contact with the spring, while at the same time the full pressure of steam in the boiler acts upon the spring, tending to straighten it. The end or ends of the spring being free to move, and connected by suitable geared rack and pinion with the pointer of the gauge, this hand or pointer is caused to move across the dial, thus indicating the pressure of steam per square inch in the boiler. When there is no pressure in the boiler the hand should point to 0.

Steam gauges should be tested frequently by comparing them wtih a test gauge that has been tested against a column of mercury.

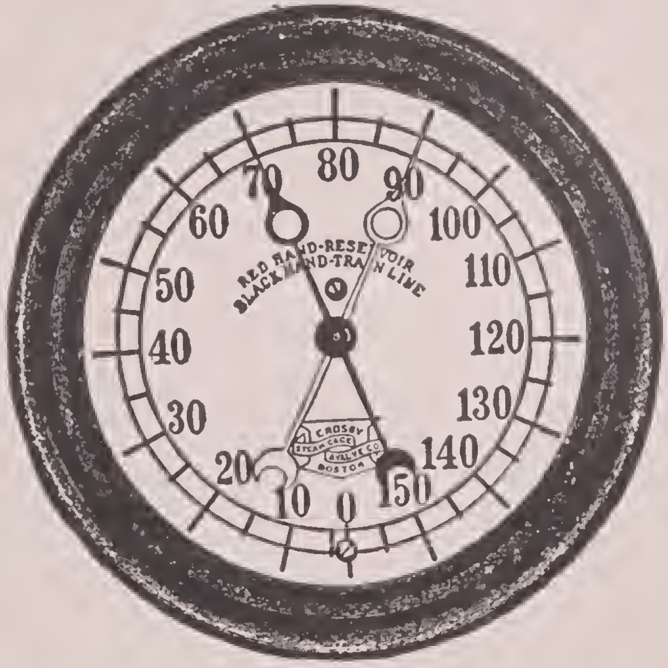


Fig. 94. Crosby Duplex Gauge.

Crosby Improved Locomotive Pressure Gauge. Attention is called to the cut, Fig. 93, of the Crosby improved locomotive pressure gauge, showing the Bourdon tube springs and their mechanism. It will be observed that the tube springs are attached to the socket and to the tips, to which the lever mechanism is connected in a new way.

The method practiced is to have these attachments of the tube springs made by means of solder or other metal of low-fusing point, and, while this may be safe in all

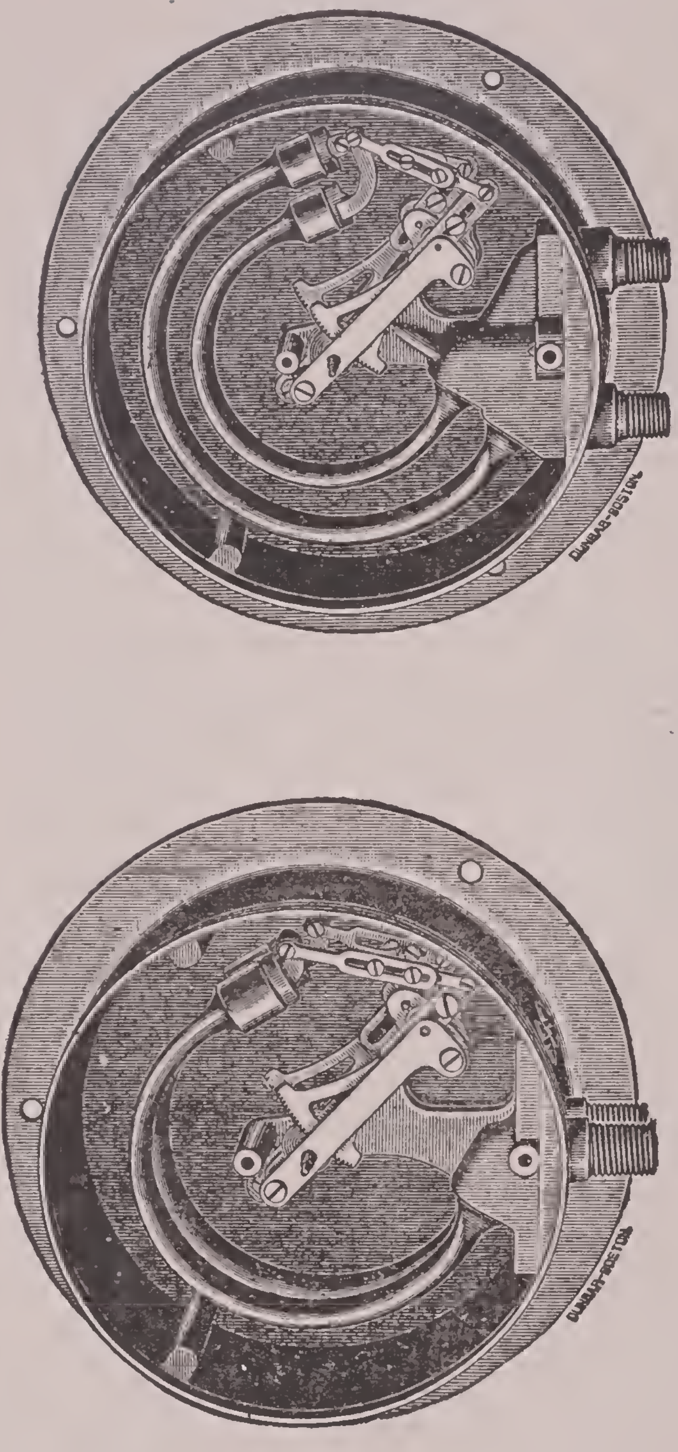
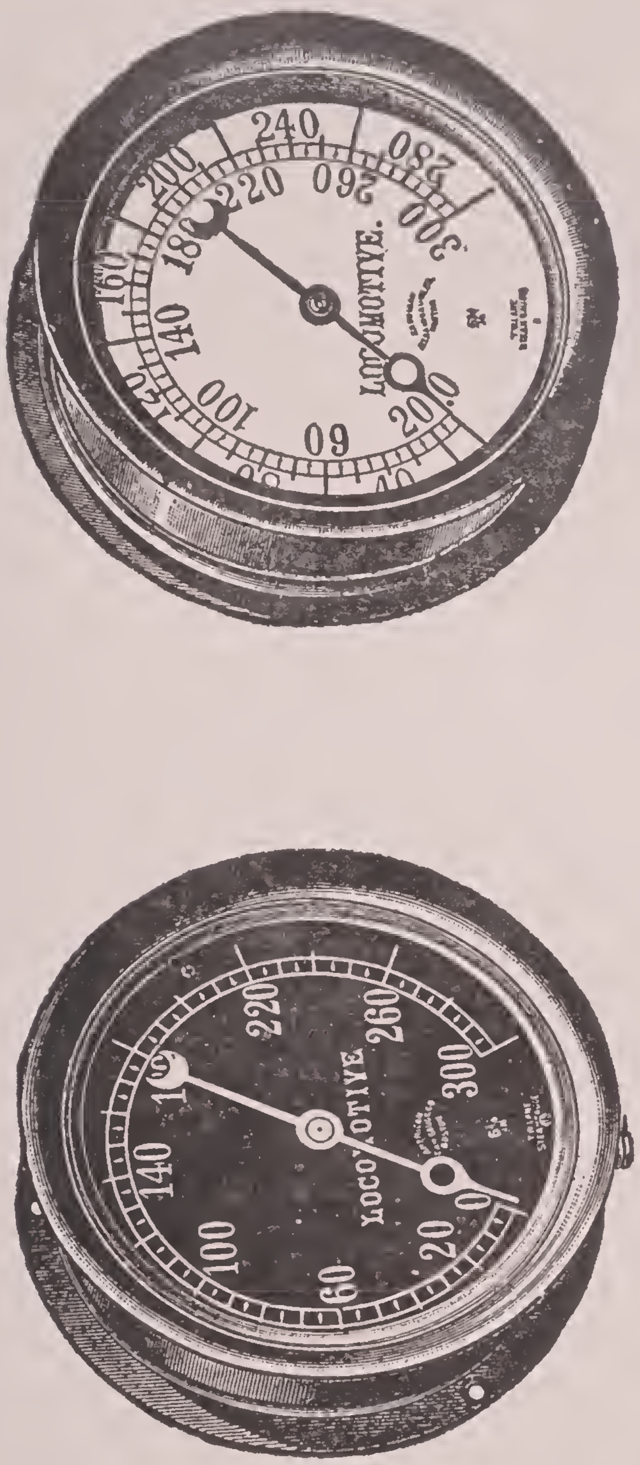


Fig. 95. Crosby Duplex Gauge, Sectional View.

low-pressurage gauges, or where in their location in use they are not subjected to great heat, yet it is hazardous where high pressures of steam are to be measured by them, especially where there is liability of the admission of such steam into the tube springs. In such case the



Black Dial. White Dial.

Fig. 96. The American Locomotive Pressure Gauge

soldering material may soften, and under the high pressure be forced out, causing a leak and the destruction of the gauge.

In the Crosby improved locomotive pressure gauge, the tube springs are connected at each end with their respective parts by screw threads, without the use of any soldering material whatever, thus insuring tight joints under all conditions of heat and pressure.

In addition to the improved Bourdon tube springs so employed, careful attention has been given to the lever mechanism which transmits the free movements of these Bourdon tube springs to the index. They have been designed and constructed not only to convey the full movement of the tube springs, but so that they may be renewed without difficulty in case of repairs or reconstruction.

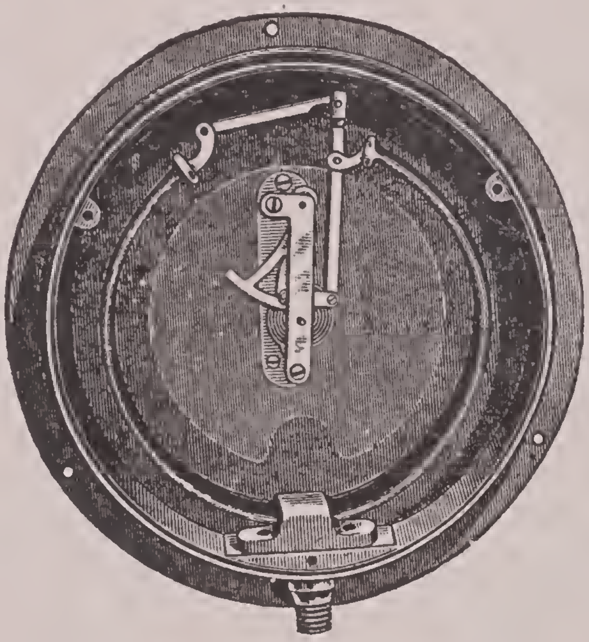


Fig. 97. American Pressure Gauge—Sectional View.

American Locomotive Gauge, with non-corrosive movement, Figs. 96 and 97. It is constructed of metals of superior quality, to withstand the constant vibration to which it is subjected. The spring is made of very heavy seamless drawn tube of superior quality. The connections are made of hard phosphor bronze. The movement is made with a wide faced sector, which will outwear three of the ordinary sectors. The pinion and sector shafts are made of hard phosphor bronze, and the hair spring is made of bronze, making the gauge non-corrosive, rigid, and adding materially to the life of the gauge.

THE WATER GLASS, AND GAUGE COCKS.

Equally as important as the steam gauge, is the water glass, or water gauge, on all steam boilers, but especially so on the locomotive boiler. The water glass and gauge cocks constitute the only indicator by which the engineer and fireman are enabled to know when the water in the boiler is at a safe height.

In fact, so far as regards safety to life and property, this indicator is in reality of more importance than the steam gauge is, owing to the fact that, in addition to the steam gauge for controlling the pressure, there is the pop valve, which automatically allows the excess steam to escape, even though the steam gauge should be out of order, thus preventing an explosion of the boiler from high pressure steam, while on the other hand, should the steam pressure drop below the working point, no serious results would follow except inconvenience in handling the train.

But the situation changes when we come to consider the function of the water glass. Here is a device upon which the enginemen rely for information regarding the exact height of the water in their boiler, and should it make a false showing as a result of its valves becoming clogged with scale or mud, or it may be on account of wrong connections, the consequence is that one of two dangerous extremes is liable to be reached, viz., either too much

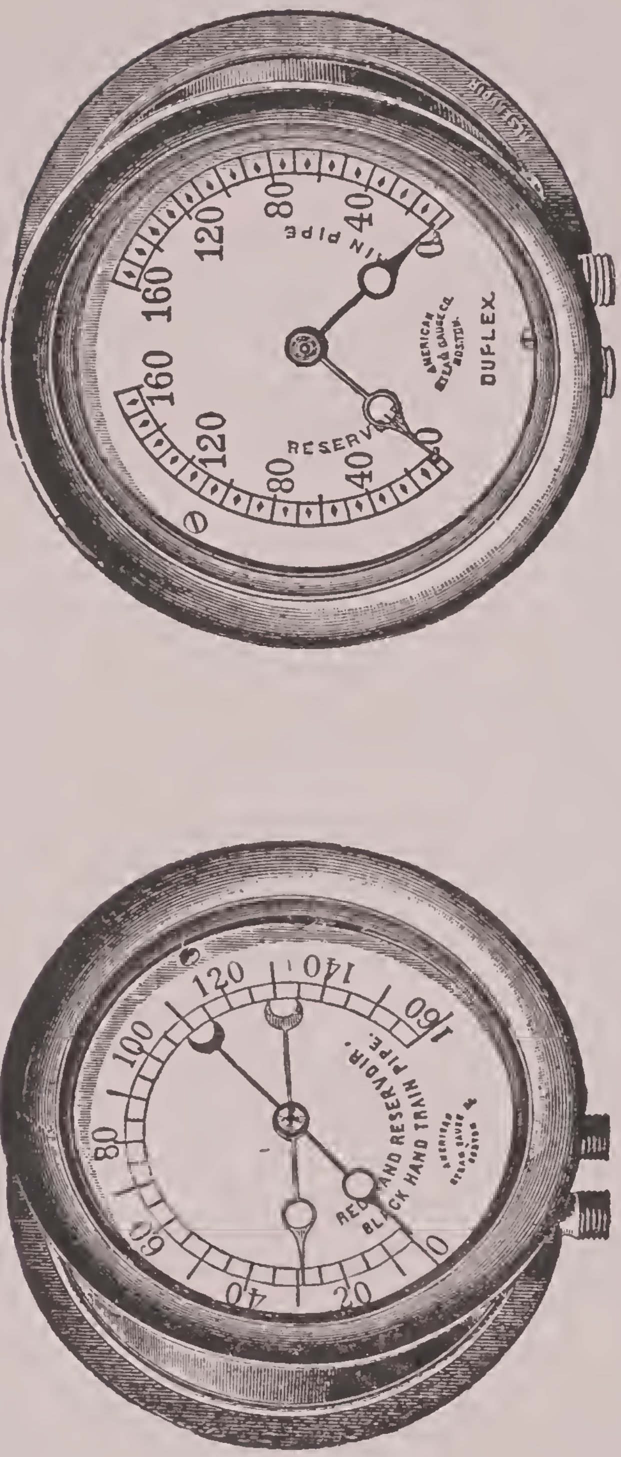


Fig. 98. American Duplex Air-Brake Gauge, Westinghouse Style.

water in the boiler, and the engine working water, or too little water in the boiler, and a burned crown sheet.

One cause of erratic action on the part of a water glass is a reduction of pressure in the top end of the glass. This is liable to occur if the top end of the glass is connected to the turret, or, in fact, is supplied with steam from any other source except an independent cock on the boiler head.

There should be a small dry pipe inside the boiler leading from the top cock of the water glass to the dome. An even pressure of dry steam will thus be supplied to the top of the water glass, thus preventing the excessive jumping up and down of the water in the glass.

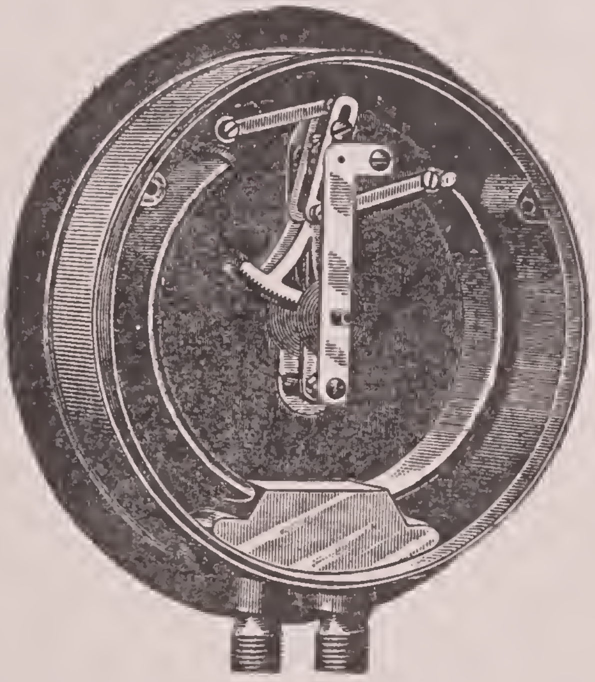


Fig. 99. American Duplex Air-Brake Gauge, Westinghouse Style.

On the other hand if the top end of the glass is connected in such a manner that the steam supply is taken from the turret, or any other source where it would be likely to be influenced by the draft of steam used by the injectors when in operation, the result would be a slight reduction of pressure in the top end of the glass and the water in the glass would rise above the level of the water in the boiler.

A very slight decrease in the steam pressure in the pipe leading to the glass will cause this trouble.

With reference to the location of the water glass and gauge cocks, the Railway Master Mechanics' Association recommend that, the lowest visible part of water glass and the lowest gauge cock be not less than three inches above highest point of crown sheet for curved and flat crown sheets, and that water glass and gauge cocks be as near vertical center line of boiler as they can conveniently be located without having gauge cocks out of reach of engineer.

They also recommend 8 inches exposed length of water glass and three gauge cocks with vertical spacing 3-inch centers. Replies received by the committee indicated that crown sheets sloped three-eighths of an inch per foot represented very general practice, and that this slope has proved satisfactory. For various reasons an automatic low-water detector seemed not to be a desirable attachment to locomotive boilers.

As regards the proper height for carrying water in the boiler, Mr. W. G. Wallace, past president, Traveling Engineers' Association, makes the following suggestions:

Wet steam is less effective than dry steam. When the water is too high in the boiler it is carried into the dry pipe and to the valves and cylinders when throttle is open. More water is used, more fuel consumed and the efficiency of the engine is decreased. The wet steam or water carried over into the steam chests and cylinders destroys the lubrication and increases the friction on the valves and cylinders. Keep your crown sheet wet, but use steam as dry as possible to make time or pull tonnage always.

TANK WATER STRAINER.

The illustration, Fig. 99a, is a sectional view of a strainer and valve designed and patented by Mr. Joseph McAfee of West Philadelphia, Pa.

Mr. McAfee says of his invention:

"Undeniably the prompt and reliable feeding with water of the boiler of a locomotive engine is one of the prime conditions for the reliability of the railway service in general. Reliable train service cannot be had without the assurance of a reliable feed water supply to the boiler of the locomotive under all conditions and at all times, as this is the foundation for the prompt and ample generating of the necessary motive power. Still it is a fact that designers of locomotive engines, as a rule, do not pay that attention to the injector which its importance calls for, and beyond specifying the type and size desired, hardly any other attention is paid to its most desirable location and other points, with a view to assisting in the development of the best qualities and assuring reliable service.

"Injectors, as any other product of human endeavor, are subject to defect and failure; the very mechanical nature of the instrument calls for consideration in its arrangement and that of its accessories which, when properly considered at the time of building the engine, would go a long way toward preventing annoyance, expense, and sometimes serious inconvenience. It is perhaps within the province of this paper to point out some features in this direction. The little conical copper strainers inside of the feed pipes should be abolished, as they are a nuisance and the cause of more trouble than they

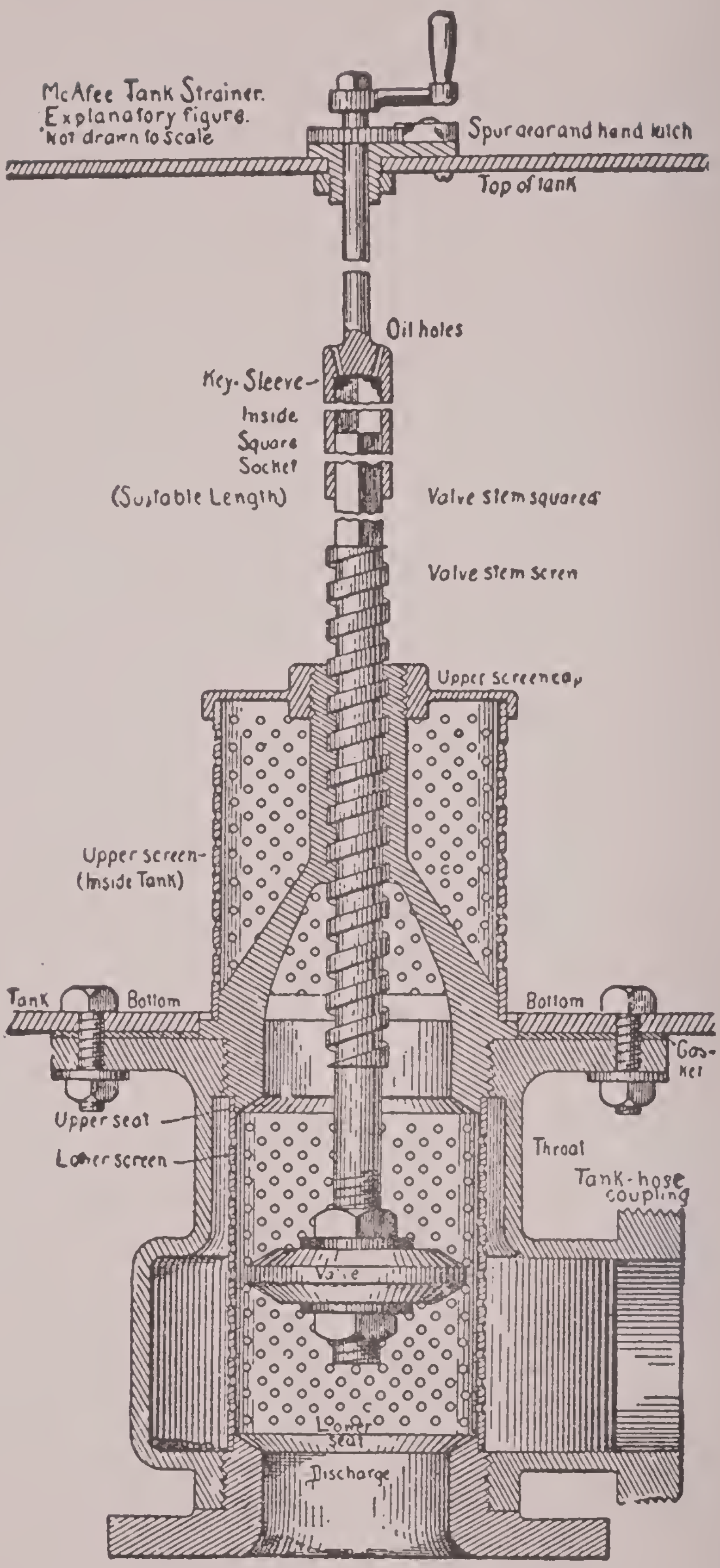


Fig. 99-a. The McAfee Tank Water Strainer and Valve Combined.

get credit for. If a premium had been put upon designing something to readily catch and retain any dirt in such manner as to materially reduce the water supply, these strainers would undoubtedly have received the first prize. The very fact that they are inside of the pipe is objectionable. The strainer should be outside the pipe. The size of the strainer should be such that, even if half filled with foreign matter, it would retain the full pipe capacity. It should also be so designed that it could be readily cleaned at any time and in a very few seconds. Such strainers can be obtained in the market, and their cost would be more than compensated for by avoiding troubles often caused by their absence. The free and unrestricted passage of the water from the tank to the injector on a locomotive is of the utmost importance. It is the experience of the engineer and those who have to deal with the question that ordinary strainers are liable to become stopped up and obstructed with the accumulations of dirt and other matter which gets into the tank and prevents the proper flow of water to the injector, thereby causing a great deal of trouble and loss of time.

"To obviate this difficulty the McAfee improved strainer and valve has been designed, which, while retaining the full pipe sizes in the perforated strainer, is spacious enough to allow for the accumulation of the obstructing substances before described, during the ordinary run of the locomotive, and still allow a free passage for the water from the tank to the injector. By the use of this improved strainer the reducing of the capacity of the injector from a short water supply will be altogether avoided, and the injector will be permitted by the continuous flow of the water in full volume from the tank to throw its full capacity and reduce the chances of its breaking to an infinitesimal degree. The very large outlet at the bottom will enable the engineer to clean the strainer in the shortest time possible."

POP VALVES.

Safety Valves. One of the prime causes of boiler explosion is the gradual and insidious increase of the pressure of steam beyond the endurance of the boiler; but to every boiler there is a limit of pressure within which it is substantially safe. This point should be ascertained by hydraulic test annually, and no excess of pressure beyond this limit should be allowed at any time. The only sure preventive is a safety valve which is all

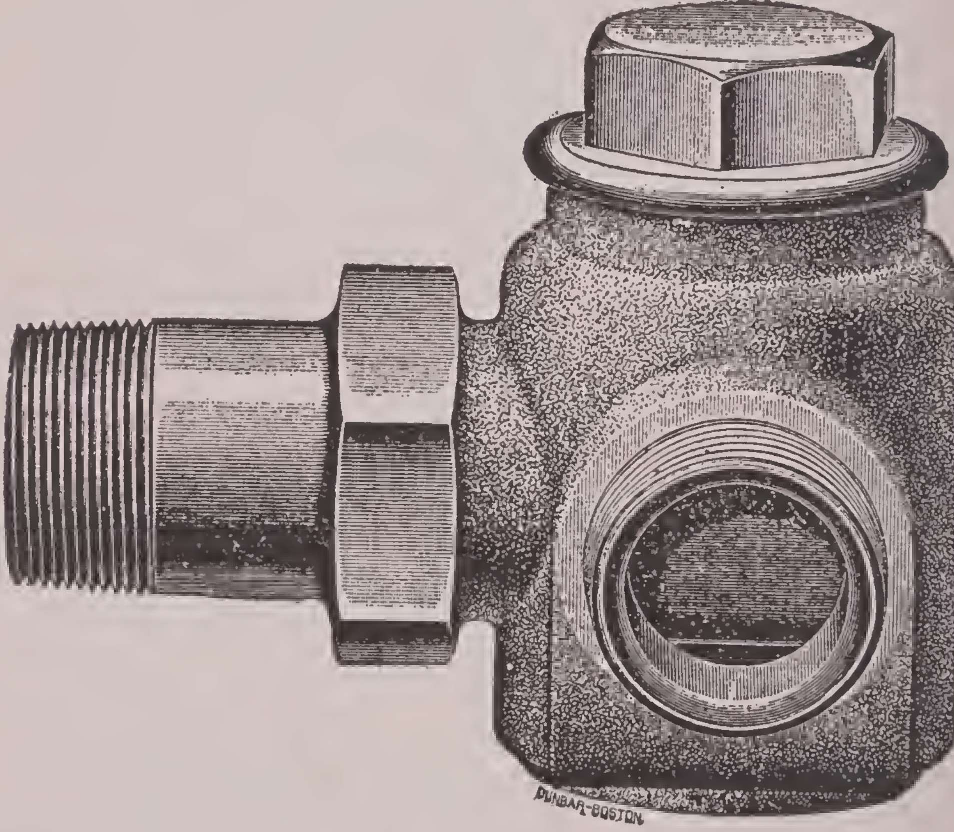


Fig. 100. Crosby Spring-Seat Locomotive Check Valve.

its name implies. The diameter of a safety valve is not a test of its efficiency. A valve is effective in direct proportion to its lift, other things being equal. The higher the pressure of steam, the less will a common safety valve lift; at most, its lift is very slight, and with the increasing pressure of steam, the lift will not increase sufficiently to relieve the boiler under all circumstances; but the pressure can and may increase until an explosion occurs, while the valve is in operation. The common safety valve has much to answer for. Owing to the great friction of its parts, it will not open until the pressure is above what it is set at; it will continue to blow after the pressure of the steam has fallen far below the point of opening; it wastes large quantities of valuable steam in operation. There are other grave faults, but these stated are sufficient to condemn it. Instead of standing guard over the boiler, a sentry has to be set over it, and should he by accident, ignorance or negligence, not properly attend to his duties, the boiler is without any safeguard whatever. Hence the importance of any device which shall reduce the danger to a minimum. A safety valve which is automatic, certain in its action, prompt in opening and closing at the required point of pressure, and which can be fully relied upon to relieve the boiler under all circumstances, is what is necessary.

THE CROSBY LOCOMOTIVE POP SAFETY VALVE. Fig. 101. *Description of the Valve.* The valve proper B B rests upon two flat annual seats V V and W W on the same plane, and is held down against the pressure of steam by the steel spiral spring S. The tension of this spring is obtained by screwing down the threaded bolt L at the top of the cylinder K. The area contained between

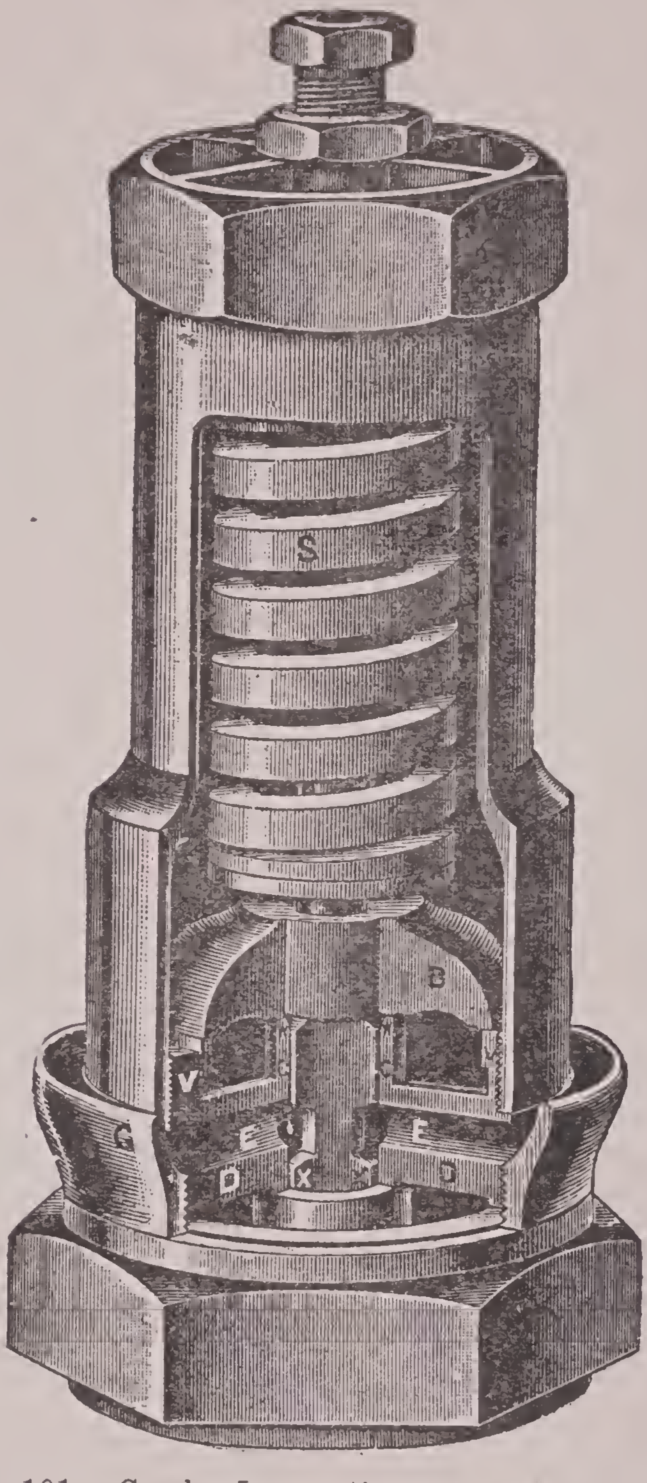


Fig. 101. Crosby Locomotive Pop Safety Valve.

the seats W and V is what the steam pressure acts upon ordinarily to overcome the resistance of the spring. The area contained within the smaller seat W W is not acted upon until the valve opens.

The larger seat V V is formed on the upper edge of the shell or body of the valve A. The smaller seat W W is formed on the upper edge of a cylindrical chamber or well C C, which is situated in the center of the shell or body of the valve, and is held in its place by arms D D, radiating horizontally, and connecting it with the body or shell of the valve. These arms have passages E E for the escape of the steam or other fluid from the well into the air when the valve is open. This well is deepened so as to allow the wing X X of the valve proper to project down into it far enough to act as guides, and the flange G is for the purpose of modifying the size of the passages E E and for turning upward the steam issuing therefrom.

Action of the Valve when Working under Steam. When the pressure under the valve is within about one pound of the maximum pressure required, the valve opens slightly, and the steam escapes through the outer seat into the cylinder and thence into the air; the steam also enters through the inner seat into the well, and thence through the passages in the arms to the air. When the pressure in the boiler attains the maximum point, the valve rises higher and steam is admitted into the well faster than it can escape through the passages in the arms, and its pressure rapidly accumulates under the inner seat; this pressure, thus acting upon an additional area, overcomes the increasing resistance of the spring, and forces the valve wide open, thereby quickly relieving the boiler. When the pressure within the boiler is lessened, the flow of steam into the well is also lessened, and the pressure therein diminishing, the valve gradually settles down; this action continues until the area of the opening into the well is less than the area of the apertures in the arms, and the valve promptly closes.

The point of opening can be readily changed while under steam by screwing the threaded bolt at the top of the cylinder up for diminishing, or down for increasing, the pressure.

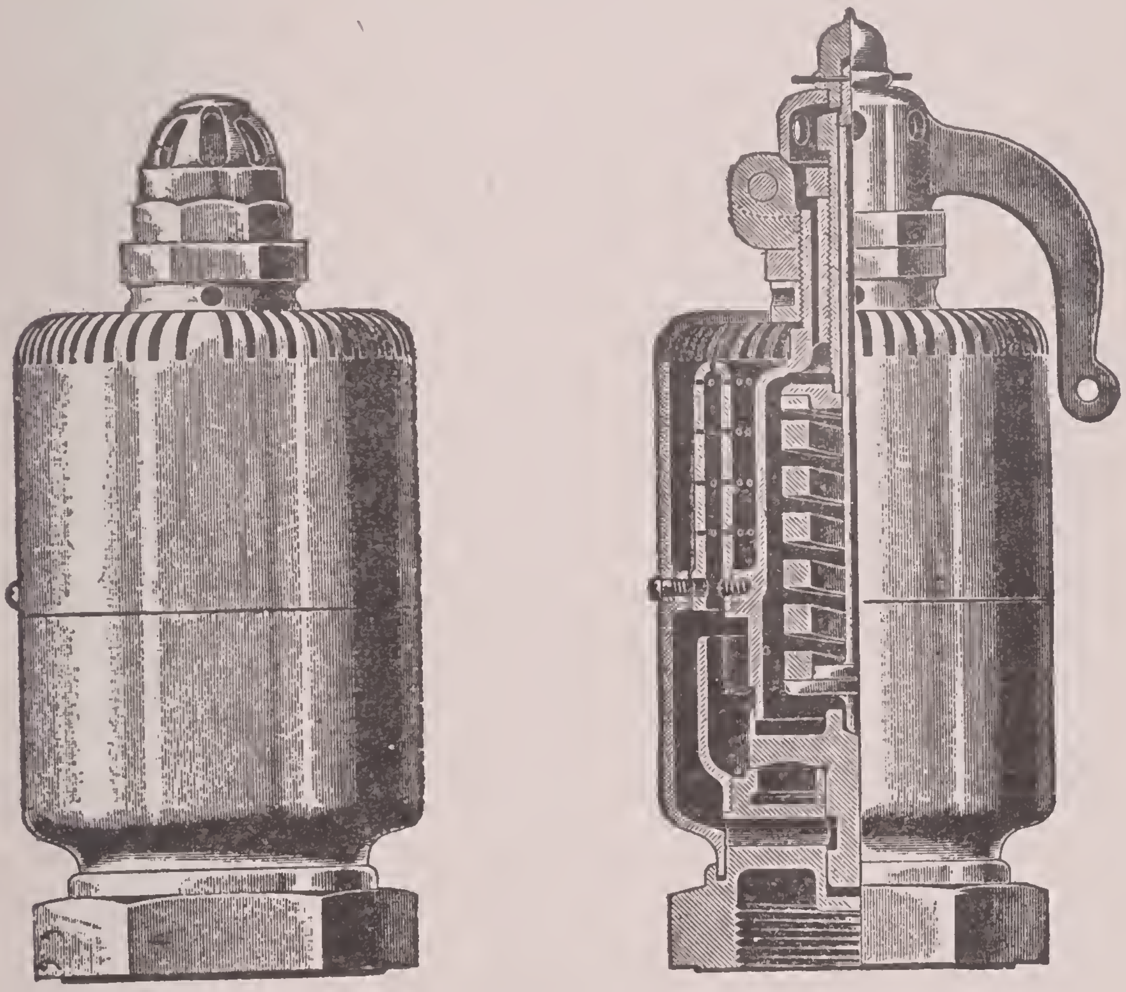
The seats of this valve are flat, and do not cut or wear out and leak so readily as beveled seats. The valve is made of the best gun metal.

DIRECTIONS. *Setting.* Screw the head-bolt which compresses the spring up for diminishing, or down for increasing, the pressure, until the valve opens at the pressure desired, as indicated by the steam gauge; secure the head-bolt in this position by means of the lock-nut; for regulating the loss of escaping steam, turn the screw ring G up for increasing, or down for decreasing it.

Caution. Care should be taken that no red lead, chips, or any hard substance be left in the pipes or couplings when connecting the valve with the boiler. Never make a direct connection by screwing a taper thread into the valve, but make the joint with the valve by the shoulder.

Repairing. This valve, having flat seats on the same plane, is very easily made tight if it leaks, by following these directions, viz.: With an ordinary lathe slightly turn off the two concentric seats of the valve and valve shell or base respectively, being careful that this is done in the same plane and perpendicular to the axis of the valve. The valve will then fit tightly on one valve shell. If no lathe is at hand, then grind the valve proper on a perfectly flat surface of iron or steel, until its two bearings are exactly on a plane and with good smooth surfaces; then take the shell and grind its seats in precisely the same manner; rinse both parts in water and put together, and the valve will be found to be tight; to ascertain when the bearings are on the same plane, use a good steel straight edge. Do not grind the valve to its seats on the shell by grinding them together, but grind each part separately as above stated.

The Crosby pop safety valve and muffler combined, possesses outside means for adjusting or regulating it under changes of pressure, without disturbing its connections or parts.



External View. Sectional View with Lever.

Fig. 102. Crosby Muffled Locomotive Pop Safety Valve.

American Improved Locomotive Muffled Pop Safety Valve. This valve has many new features, one of which is the manner in which it is adjusted; both the blowing-off pressure and the blow-down are adjusted from the top of the valve without removing the muffler casing—simply remove the small top cap. The blowing-off pressure is adjusted by means of a compression screw, the same as is used in all locomotive valves. The blow-down is adjusted by means of a hexagon nut just below the compression screw. This nut is connected by means of a yoke and standards to the relief ring, which is raised or lowered to adjust the blow-back where the case may require, the nut acting as a swivel. The same lock-nut locks both the compression screw and the blow-down nut, as shown in the sectional cut, Fig. 103.

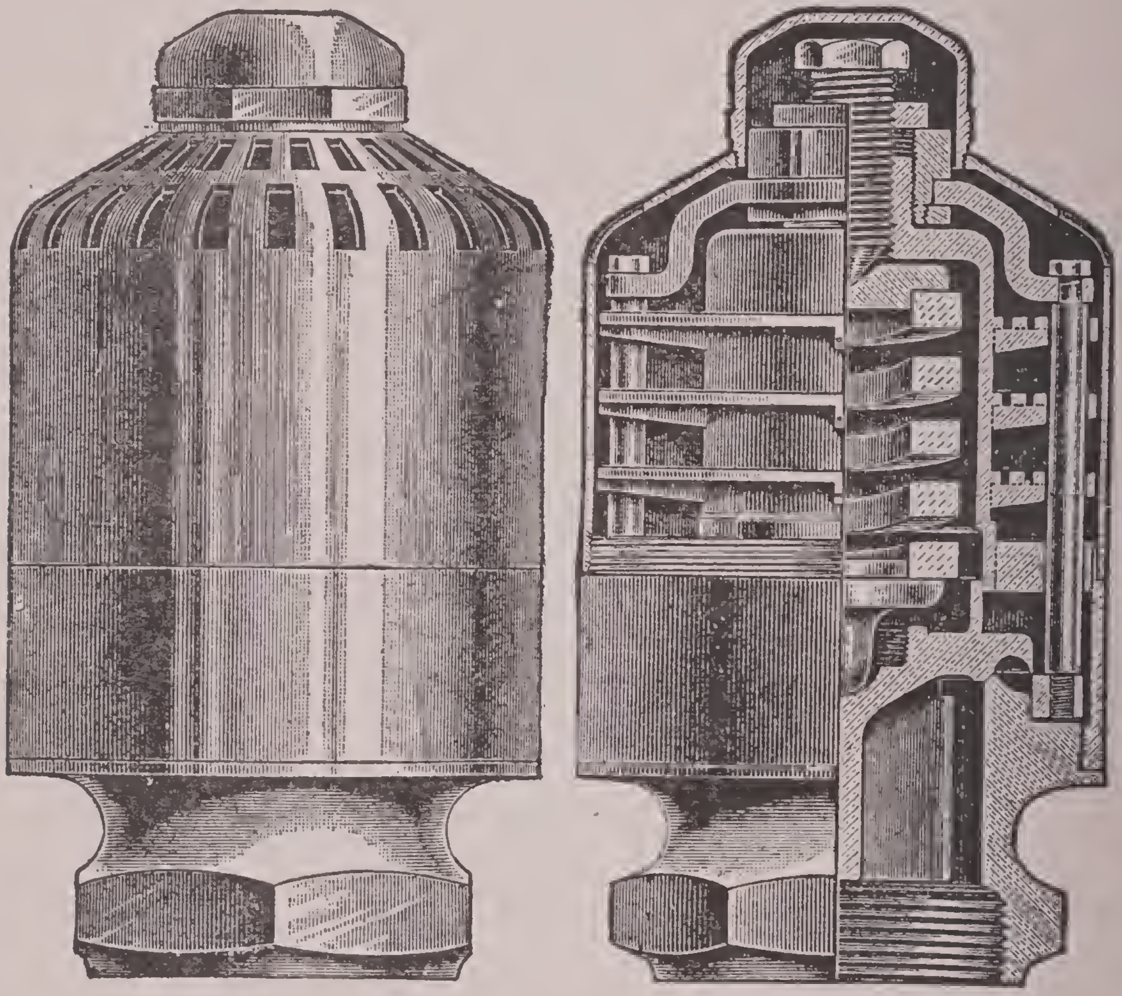


Fig. 103. American Locomotive Safety Valve.

The noise of the escaping steam is lessened by the muffling device, as shown in cut.

Springs. These springs are made of the highest grade of steel, carefully tempered, and are ground square on the end. Each spring is tested to double its capacity.

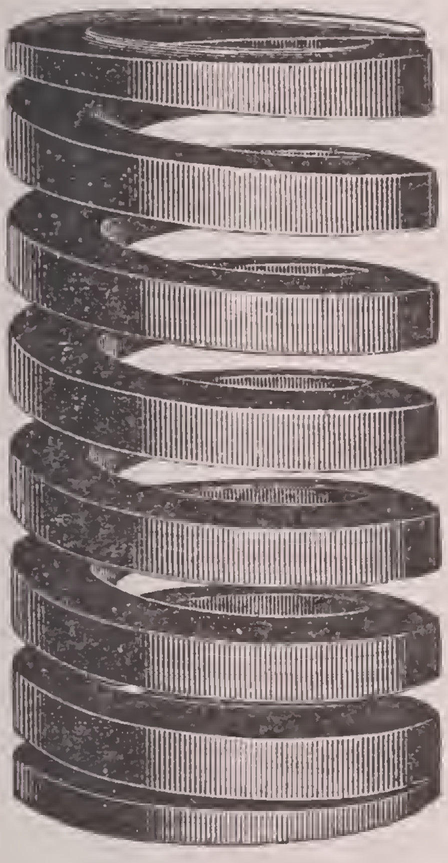
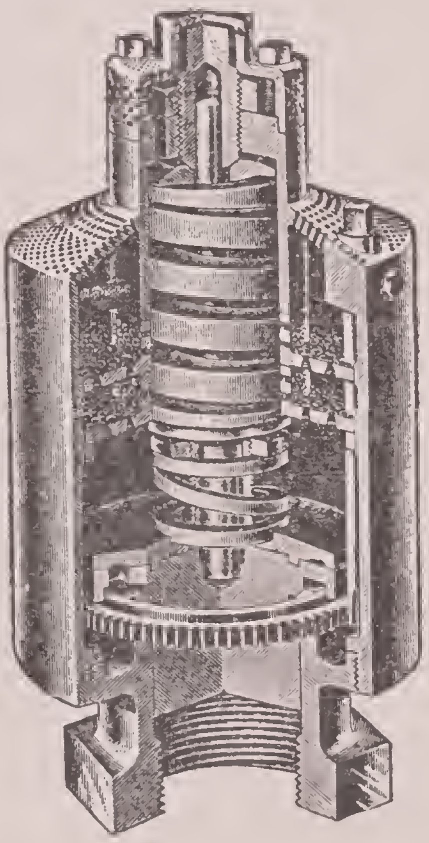


Fig. 104. Spring for American Locomotive Pop Valve.



'ig. 105. Crane Pop Valve—Sectional View.

CRANE'S PATENT IMPROVED POP SAFETY VALVES. Fig. 105. Their construction embodies a self-adjusting feature automatically regulating the "pop" of the valve; in other words, maintains the least waste of steam between the opening and closing points, an improvement which will be readily recognized, as there is no necessity of re-adjusting to regulate the "pop" on reasonable changes in the set pressure.

This is more clearly explained, as follows: In all pop safety valves it is necessary to have a "pop," or huddling chamber into which the steam expands when main valve opens, thereby creating an additional lifting force proportionate to this increased area and greater than the force of spring, thus holding the valve open until pressure is relieved. Means must also be provided to relieve this "pop" chamber of pressure in order to allow the valve to close promptly and easily. This is accomplished by a self-adjusting auxiliary valve and spring, which are entirely independent of the main valve and spring; and to further explain their operation, the steam in "pop" chamber finds a passage through holes or ports into an annular

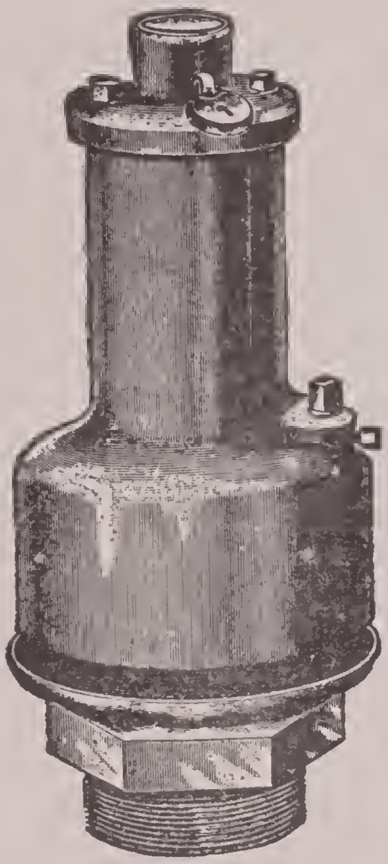


Fig. 106. Crane Muffled Pop Valve.

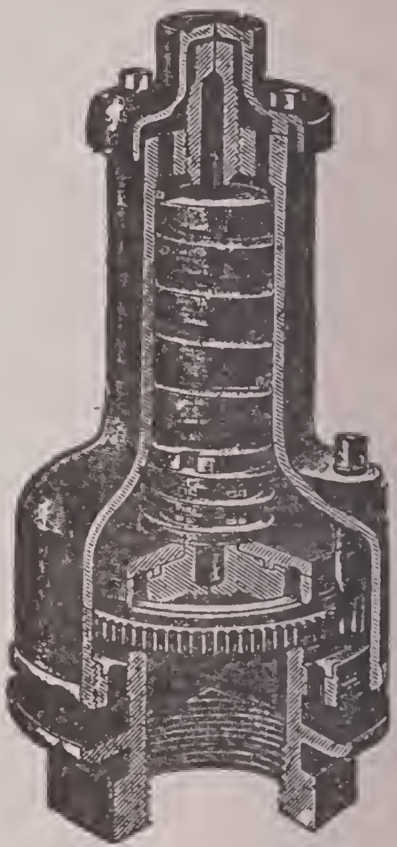


Fig. 107. Crane Muffled Pop Valve—Sectional View.

space provided in the auxiliary valve or disc, and by reason of the light auxiliary spring, this pressure lifts the auxiliary valve and allows the steam in "pop" chamber to gradually escape, thus permitting a greater range in setting pressures with the least waste of steam and at the same time supplying a cushion or balancing medium, thereby preventing any chattering or hammering and affording the easiest possible action in closing.

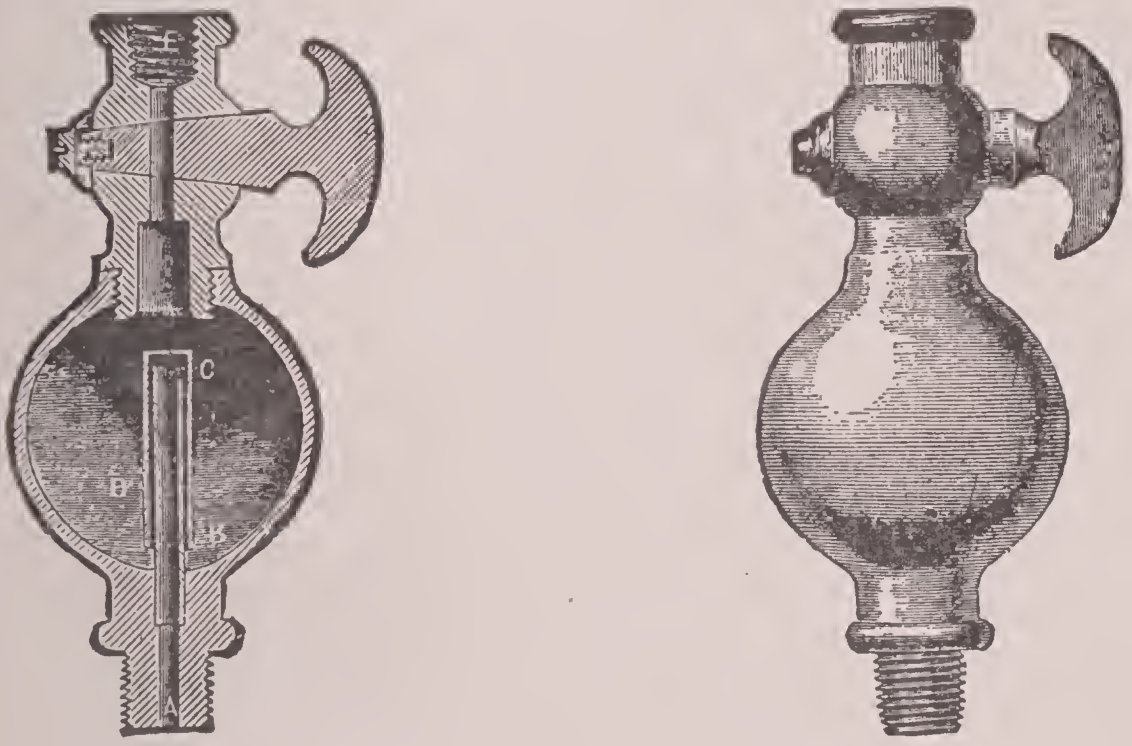


Fig. 108. **Prindle's Patent Syphon Cocks.**

To change pressure, unscrew the top bolts and remove the cap, slacken lock nut; to increase pressure, turn screw plug down (to the right); to decrease pressure, turn screw plug up (to the left), then tighten lock nut.

Should the valve waste too much steam between the opening and closing point, turn the outside pop regulator to the left until the desired waste is obtained. Should it work too close, turn regulator to the right for greater waste.

CRANE'S PATENT LOCOMOTIVE MUFFLER POP SAFETY VALVE. Fig. 106. This valve is made with the outside "pop" regulator conveniently arranged at the top of the valve, for quick and easy adjustment, and while the boiler is under pressure.

TABLE 14.

Size Valves, inches	2½	3	3½
Dome Connection, inches	2	2½	3

THE KUNKLE LOCK-UP POP SAFETY VALVE. Fig. 109. The pressure screw of this valve is made of hard tempered brass and can be removed at any time without being troubled with rust. The whole of the valve is made of brass throughout, with the exception of the pressure spring, which is made of the best steel and is thoroughly excluded from steam or dampness, making every part of the valve adjustable and free from rust. The spring is set between two tapered points, as will be seen by reference to open view. Another point in its favor is the uniform bearing of the valve upon its seat by reason of its long ribbed chamber, which guides the valve so accurately as not to allow it to cap on one side, thereby preventing the steam from cutting away the seat.

The valve with its regulator can be adjusted to go off suddenly without a loud pop or without loss of boiler pressure.

THE KUNKLE LOCK-UP POP SAFETY VALVE AND MUFFLER COMBINED. Fig. 110. It relieves itself of all over-pressure, without raising above what it is set at; will close down upon its seat without losing any of the desired or fixed pressure, and by means of its lock-up device, so ingeniously constructed, all unauthorized persons are prevented from tampering with it. It is provided with a pressure screw with the tapering point resting in the center of the top plate on top of the spring, and is locked with a key, and a jam-nut holding it firmly to its place, which makes it perfectly safe from being tampered with.

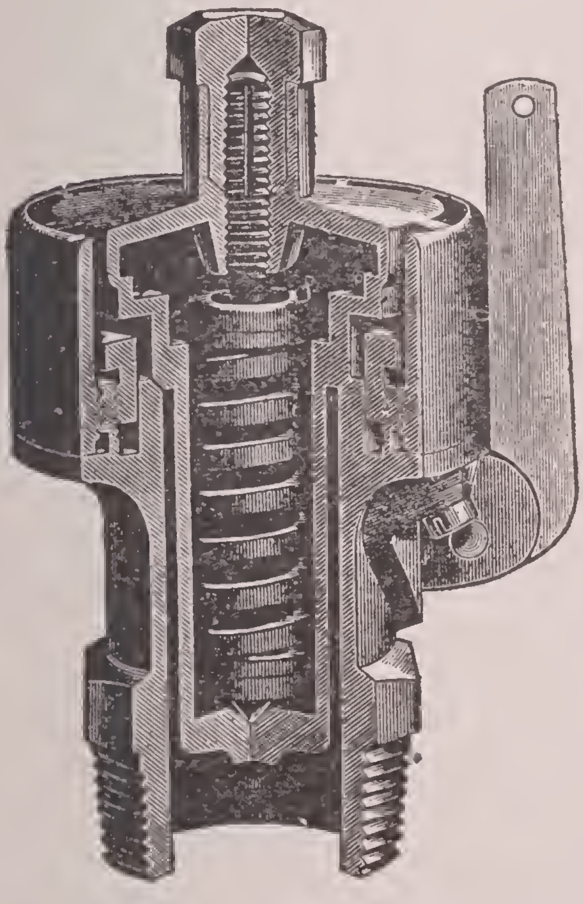


Fig. 109. Kunkle Pop Valve for Portable and Stationary Boilers.

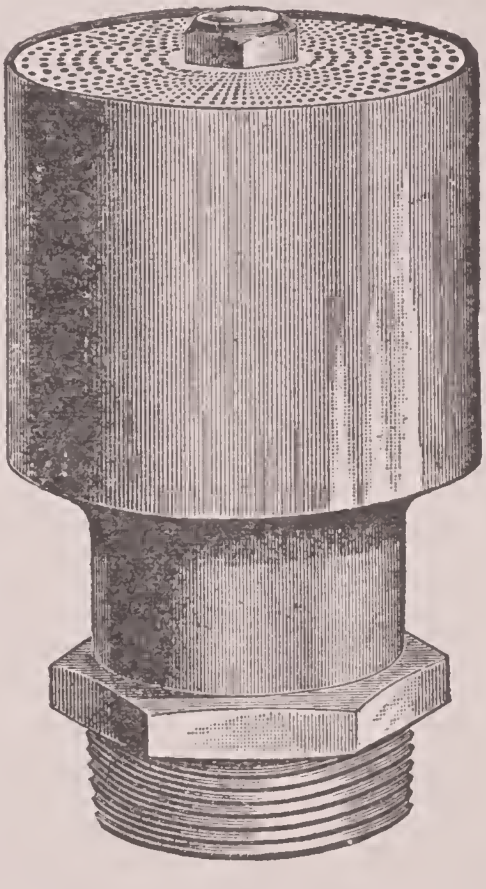


Fig. 110. The Kunkle Pop Valve for Locomotive Boilers.

SUPERHEATING STEAM FOR LOCOMOTIVES.

Superheated steam is steam heated to a temperature above that due to its pressure. The temperature of steam in contact with water depends on the pressure under which it is generated, as shown in steam tables, while superheated steam is at a higher temperature.

Steam is superheated by passing through a system of pipes or coils that are placed in the smokebox for this purpose, and the steam in passing from the boiler to the cylinders absorbs the heat from the smoke and gases as they are drawn through the flues and stack, thus increasing its temperature. Superheated steam therefore gives a higher efficiency of the engine, as there is less loss of heat by condensation when it comes in contact with the walls of the cylinders. There are many types of superheaters, and the usual benefit derived from their use is claimed to be about 13 per cent higher efficiency.

It is surprising that the advantages arising from the use of superheated steam should not have led to its earlier use on the locomotive; for it is only during the past two or three years that the superheater has begun to establish itself in locomotive practice. This development we owe chiefly to the Germans, who, with their characteristic thoroughness, are just now paying particular attention to the question of locomotive efficiency. The advantage of the use of superheated steam is that, by preventing cylinder condensation, it renders it possible to obtain from a simple locomotive an economy that compares favorably with that of the compound locomotive. It also permits of the use of a lower boiler pressure without any appreciable sacrifice of economy. This fact should render the superheater particularly attractive to the American master mechanic, to whom the high pressures which are now common are a source of increasing trouble and anxiety.

The great increase in boiler pressure has been one of the striking features in the recent development of the American locomotive. The most rapid increase took place during the decade 1890 to 1900, when the pressure rose from 160 to 200 pounds, to the square inch, several roads making use of the latter pressure. During the past five years 200 pounds has become common, and on some locomotives the pressure has risen to 210 pounds to the square inch; indeed, the writer has ridden on one make of compound, the needle of whose gauge was maintained at over 220 pounds to the square inch.

The increase in boiler pressure, like the increase in heating surface, has been due to the ever present demand for greater power; but as far as the gain in power due to higher pressure is concerned, it has been secured at the cost of several disadvantages, such as increased leakage loss, a marked increase in boiler repairs, and a decrease of earning capacity due to the greater time spent by the locomotive in the repair shop. Now the introduction of the superheater offers a way of escape from the dilemma, a fact which is dwelt upon by Mr. H. H. Vaughn in a paper in the proceedings of the Master Mechanics' convention, in which he states that, with the proper amount of superheat, it will be possible to return to pressures of 175 pounds or even less without loss of economy.

The Toltz Locomotive Superheater is of the smoke flue type. The large smoke flues have an inside diameter of 5″ and an outside diameter of 5.25″.

The ends of the large flues in the smoke box are enlarged to 5½" outside diameter, and are decreased in the flue sheet of the fire-box to 4⅝" outside diameter.

The superheater elements consist of seamless, cold drawn steel tubes, 1 1-16" inside diameter, and 1⅜" outside diameter. The tubes are flattened to ½" by 1 7-16" inside diameter, and 13-16" by 1¾" outside diameter, and are placed in the large smoke box flue to form a square.

The ends toward the fire-box, where a cast steel return bend is used, are left round, also the ends in the smoke box, where they are rolled into the large drop forged cast steel flanges, or clips, which connect the elements to the steam headers.

There is but one element in each smoke flue, it being double looped. The pipe is flattened in order to increase the velocity of the steam. Another reason is that, the steam flowing in a sheet will be more uniformly superheated, than it would be if flowing through a round pipe.

Another important advantage is, that due to the flattened pipes, the gas section in the smoke flue is considerably enlarged. As mentioned before, the flange or clip, into which the superheater elements are rolled like boiler flues, are connected with steam headers in pairs by one bolt. These flanges, which are either drop forged or cast steel, are manufactured solid, and are drilled out for the connection of the superheater elements, the front end of which is enlarged and threaded to receive a plug. The steam headers, which are located in a horizontal position midway between two rows of smoke flues, are of a flat section. The steam headers for the saturated steam are in front, the steam header for superheated steam being back, nearest to the front flue sheet.

As there are four rows of smoke flues, there are consequently two sets of horizontal headers that are connected on each side.

The whole is supported by brackets connected to the shell of the smoke box. The saturated steam enters through the dry pipe, on each end of the upper header. The dry pipe from the dome is split to give two connections near the front flue sheet.

The steam entering the saturated steam headers, will flow from there through the superheater elements, into the superheated steam chamber, the outlet of which is also on each side of the upper header.

The two superheated steam headers are also connected, in the same manner as the saturated steam headers. From there the steam will flow to the throttle, which in this case is located in front of the flue sheet, in the smoke box.

The throttle is a double seated poppet valve, actuated by a stem which passes through the front flue sheet, thence back through the center of the single dry pipe, to the cab.

By this construction there is always steam in the superheater elements, and for that reason it will not be necessary to use dampers for the purpose of protecting the elements from becoming overheated.

As an additional protection to the ends of the superheater elements near the fire-box, a circulation is created by a connection that is made from the casing of the throttle, which is always surrounded by superheated steam.

This connection is made by a pipe leading back into the dome, the top of which is higher than the dry pipe.

This pipe on top is closed by a valve when the engine is working steam, or when the throttle is open. When the throttle is closed, the valve on the circulating pipe will open, it being actuated by the stem of the throttle. In case the steam in the superheater elements becomes heated to a very high temperature, it will, owing to its lighter specific gravity, flow through the circulating pipe into the dome and new saturated steam will be drawn through the dry pipe into the superheater elements. At the same time, superheated steam is used for the air pump and if necessary for heating the train.

The advantages claimed for this design are:

First, to eliminate the dampers entirely. Second, on account of the flattened construction of the headers, inspection of the front flue sheets is not obstructed. Third, any of the superheater elements can be drawn out without difficulty. Fourth, there is only one bolt connection for two superheater elements. Fifth, a more uniform superheat due to the steam flowing in a sheet through the flattened superheater pipes.

The accompanying line drawing, Fig. 111, illustrates the design of the superheater and shows the boiler of a Prairie type locomotive arranged to accommodate the superheater. The weight of this locomotive on drivers is 151,000 lbs., and the outside diameter of drivers is 69 ins. Locomotives of the same class using saturated steam have cylinders 22 ins. in diameter by 30 ins. stroke, and operate under a boiler pressure of 200 lbs. With the application of the superheater the diameters of cylinders have been increased to 25¼ ins. and the boiler pressure reduced to 165 lbs. The boilers using saturated steam contain 301 tubes 2¼ ins. in diameter by 18 ft. 6 ins. long, providing a tube heating surface of 3,278 square feet. In the boiler arranged to accommodate the superheater 123 ordinary tubes were replaced by 30 tubes 5

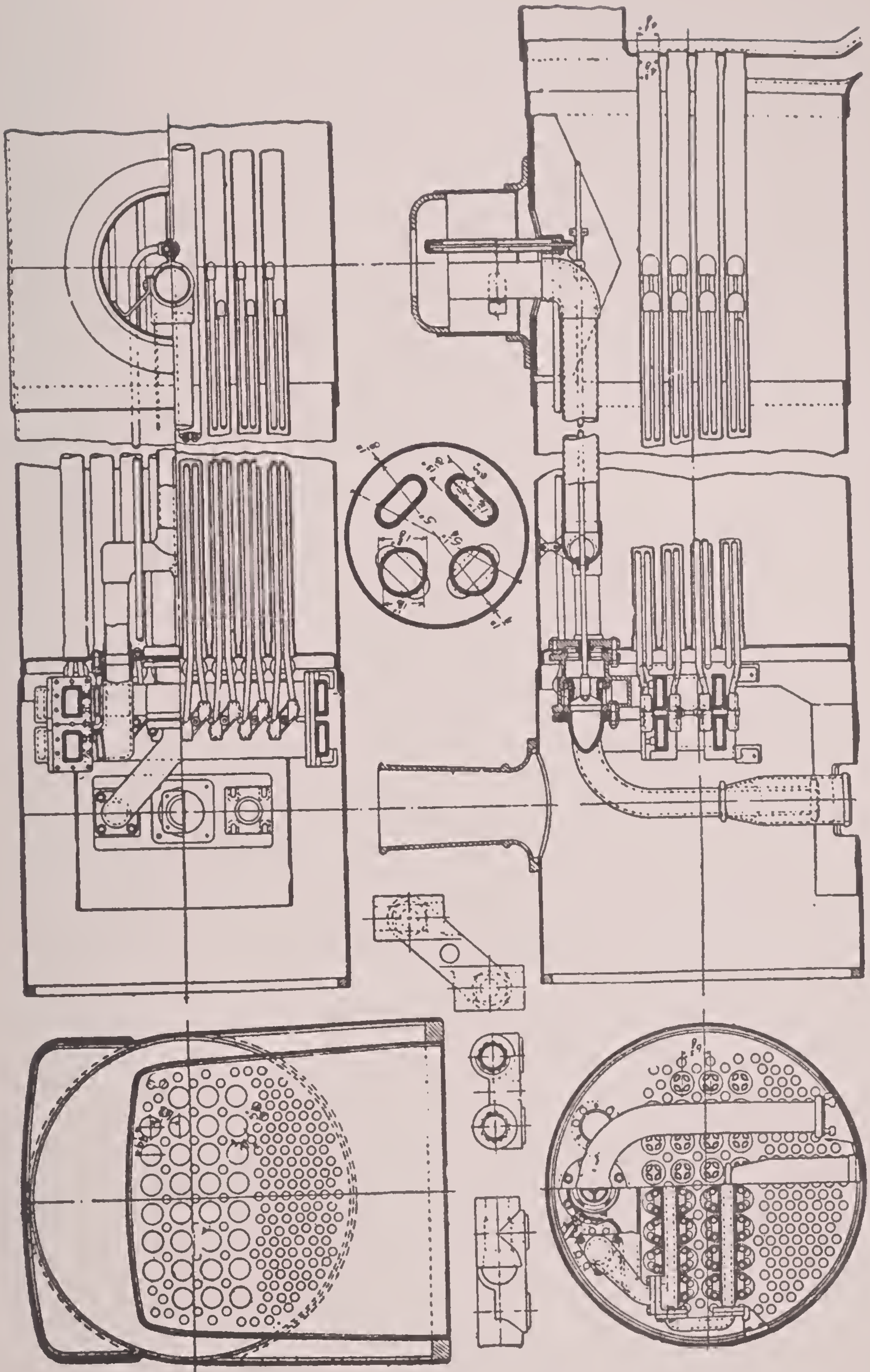


Fig. 111. Plan, Sections and Elevations of the Toltz Locomotive Superheater.

ins. in diameter. These tubes provide a surface of 600 square feet, the remaining tubes have 1,935 square feet and the heating surface provided by the superheater elements equals 755 square feet, making a total tube heating surface of 3,490 square feet. The grate area in each case is 54 square feet, and the fire-box area is 210 square feet. Then the locomotive using superheated steam has a boiler with a total heating surface of 3,700 square feet, as against a total heating surface of 3,488 square feet with those using saturated steam.

The design of the Toltz superheater has been patented by Mr. Max Toltz and is handled by the Superheating and Engineering Company, 315 German-American Bank Building, St. Paul, Minn.

Concerning the probable success of superheating steam in locomotive service, Prof. W. F. M. Goss of Purdue University presents the following very sensible conclusions:

Prof. Goss says: "The prediction of Professor Peabody, already quoted, to the effect that all superheating devices will in the end be discarded, has doubtless been generally accepted by the rank and file of American engineers. For them the problem has no mysteries. They have understood the thermodynamics of the problem. They have admitted that the use of superheated steam in engines is always attended by a more efficient cylinder action, but past experience has taught them that the difficulties in maintaining a superheater were too great to justify its continued use. They have argued that since this was true 30 years ago when steam pressures were so low that the temperature of the superheated steam was less than that of saturated steam of today, the problem of superheating is now vastly more difficult than it has ever been before. The prevalence of this view in this country naturally leads many to question whether even Germany's great progress and the more recent but equally promising start of the American Locomotive Company are as yet sufficient to insure a future for the practice. In raising this question it is not intended to minimize the value of the elaborate researches of Schmidt, Schroter and other German investigators, or of the equally valuable experience which has been gained in the application of principles. The endeavor has been made to make the fact clear that between apparently most promising and even masterful experimentation and an assured success in practice, a broad gulf is fixed, and that the voyage across is not yet finished."

Turning now from convictions based on previous experience, and approaching the subject without prejudice, it is well, first of all, to recognize the fact that when a principle in operation is correct and when it is generally understood, it is never safe to assume that the means whereby it may be utilized will forever fail to be forthcoming. The reverse is likely to be true. The efforts to use superheated steam in the cylinder of an engine are based upon correct thermodynamic principles, and hence, sooner or later, practice will embrace it. Again, it goes without saying, that with the better materials and larger experience of today, the problem of producing and utilizing superheated steam can be approached with greater certainty than was possible in the practice of many years ago. Proof of this is to be seen in the degree of success already achieved.

"Examining the question broadly, we shall find that locomotive service is more favorable to the use of the superheater than any other in which it has been tried

The installations with which we have hitherto dealt have served in stationary or marine practice. The superheater of these plants has either been a separate boiler-like device, in which no water was carried, or has been so combined with the boiler as to always be in close communication with its furnace. Under these conditions, when the engine throttle is closed, the circulation of steam within the superheater tubes ceases and the metal of the tubes, together with the entrapped steam within them, remain exposed to the undiminished intensity of the furnace action. In this manner, the tubes are often heated to very high temperatures, a result which when frequently repeated leads necessarily to a failure of the superheater. Again, when after an interval of inactivity, the engine is started, the steam which has been held back within the superheater until it has been raised to an enormously high temperature, passes on to the engine, oftentimes retaining enough of its heat to burn the lubrication and sometimes to destroy the rod packings. But all difficulties of this class which to a greater or lesser degree have appeared in the operation of every stationary engine plant using superheated steam, are doubtless avoided in the locomotive, for in this machine, the rate of combustion varies with the volume of steam used. When the throttle is open, the fire burns brightly; when it is closed, its activity is at once suppressed. When there is no steam passing within the tubes of the superheater, the gases circulating around the tubes are comparatively low in temperature, and when the conditions are so changed that the temperature of the gases becomes maximum, the volume of steam passing the tubes is greatest. Just as the draft of a locomotive responds to the varying demands which are made upon the boiler, so the volume of heat which is available for superheating varies with the quantity of steam which is to be superheated. The details of several of the designs described provide that when the blower is on, dampers are closed, which prevent the circulation of gases in the superheater, so that it is only when the throttle is open that the superheater does work. While it is my opinion that the automatic damper is in fact unnecessary, it is certainly true that with it overheating of the superheater becomes impossible. In view of the highly favorable character of all these conditions, it is likely that it will be found easier to maintain a superheater on a locomotive than in connection with any other type of engine, and, moreover, that superheating in locomotive service may be a pronounced success, while in other classes of service its future may still be problematical."

Efficiency and Power. It may be accepted as beyond question that the use of superheated steam will materially improve the efficiency of the locomotive. The saving resulting from its use is a two-fold one. For the development of a given power, the cylinders of the superheating locomotive require less steam, and as the demand for steam diminishes, the efficiency of the boiler increases, so that there is not only a saving in steam, but a proportionately greater saving in coal. The German claim that 25 per cent of the coal burned is saved by the use of superheated steam is as a general statement probably extravagant, but it is not so high as to be impossible.

Again, while economy in the use of fuel is of great importance, it is in many classes of service secondary to questions affecting the output of power. Modern conditions impose many restrictions and limitations as to the weight and dimensions of a locomotive, while at the same time they call for the development of greater power. It is, therefore, important to note that in locomotive service anything which improves the efficiency of the machine may be utilized to extend its limit of power. The power delivered per unit weight of coal burned and also the power delivered per unit weight of locomotive, is increased by the use of superheated steam. It appears, therefore, that one way in which the power of locomotives may be increased is to equip them for superheated steam.

Obviously, it should not be claimed that full advantage is to be had of the increase of economy and of power at the same instant. One effect is always sacrificed for the other. Under ordinary conditions of running, full advantage is derived from the improved economy, while in an emergency, when the locomotive must be worked at its maximum power, then at a temporary sacrifice of efficiency, limit of power may be raised.

Incidental Considerations. A fact of interest which should appear in the use of superheated steam is a decided improvement in steam distribution, which, indeed, may constitute a factor in the resulting economy. With superheated steam, the initial condensation is suppressed and the ports are required to pass only that steam which is effective in doing work, whereas with saturated steam they must pass, in addition to this, that which is represented by the initial condensation. Assuming port areas to be the same, those for a superheating locomotive are in effect from 20 to 25 per cent more liberal than for a locomotive using saturated steam. In high-speed service this becomes a matter of consequence.

An objection frequently raised against the use of superheated steam is to the effect that it increases the difficulty in cylinder lubrication. Troubles of this kind have, in fact, been common enough in stationary practice, but the fact should not be lost sight of that they have followed a period when for some reason the superheater has been overheated. Under normal conditions, an engine supplied with superheated steam has saturated steam in its cylinders, and the maximum temperature of the cylinder walls is not higher than when saturated steam is used.

It has already been shown that there is little danger of overheating a locomotive superheater, and consequently difficulties with lubrication are not to be found.

Therefore, to briefly summarize preceding statements, it appears that from an academic point of view, the conditions of locomotive service are very favorable to the use of superheated steam, that its use makes possible a better distribution of steam, it greatly improves the economic performance of the locomotive and increases the capacity of the locomotive for doing work, that the maintenance of the superheater is not likely to prove serious, nor is any trouble to be expected in securing satisfactory cylinder lubrication; that the adoption of superheated steam in locomotive service can probably be accomplished without greater difficulty than that which attends the introduction of any other important detail entering into locomotive construction, and that substantial progress has already been made in the application of the principles involved.

THE SCHENECTADY SUPERHEATER FOR LOCOMOTIVES.

The American Locomotive Co. manufacture a superheater for locomotives, which it is claimed does away with most of the objectionable features of the older types

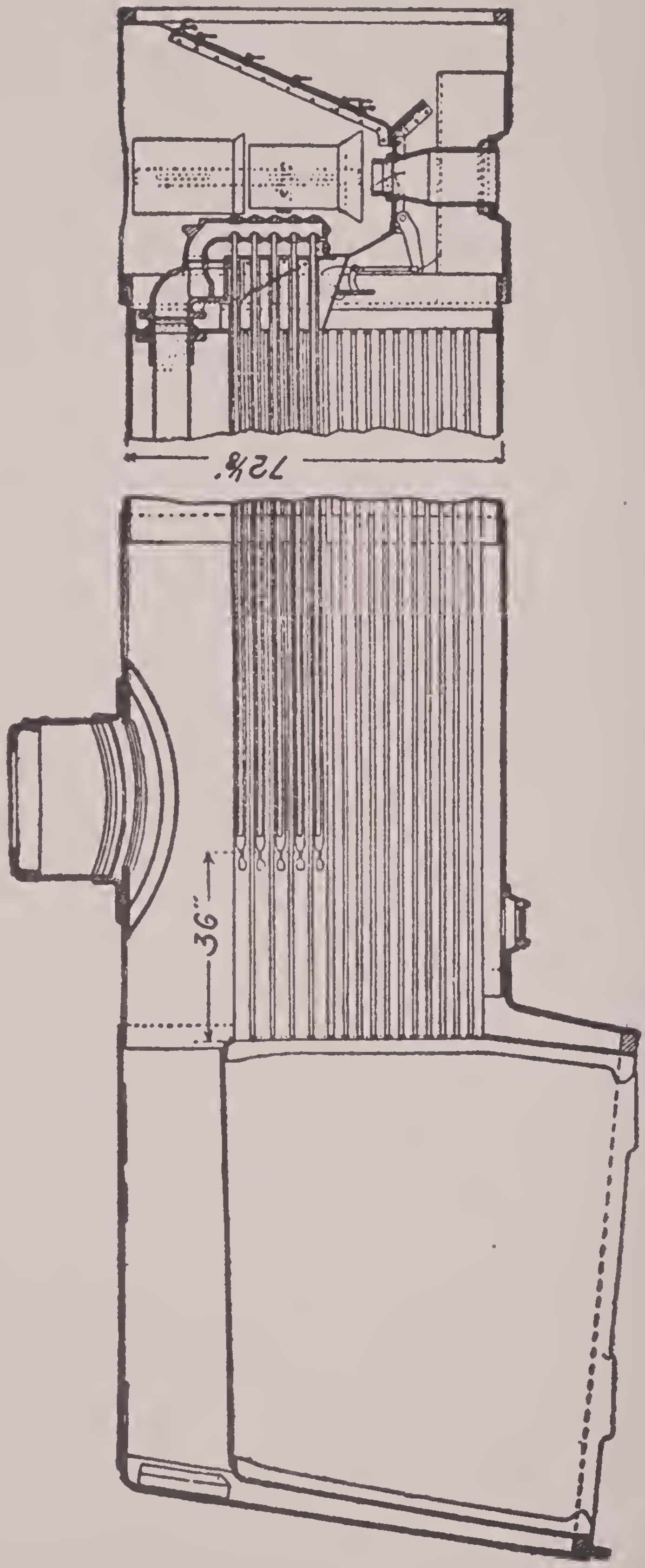


Fig. 112. Vertical Section—Schenectady Superheater.

of superheaters, among which might be mentioned, first, the use of bent tubes, and, second, the necessity of dismantling the entire superheater in order to get access to a single leaky boiler tube.

Mr. F. J. Cole, the Mechanical Engineer of the American Locomotive Co., is the designer of this superheater, which is known as the Schenectady superheater.

Mr. Cole has introduced several new features, which apparently have their merits.

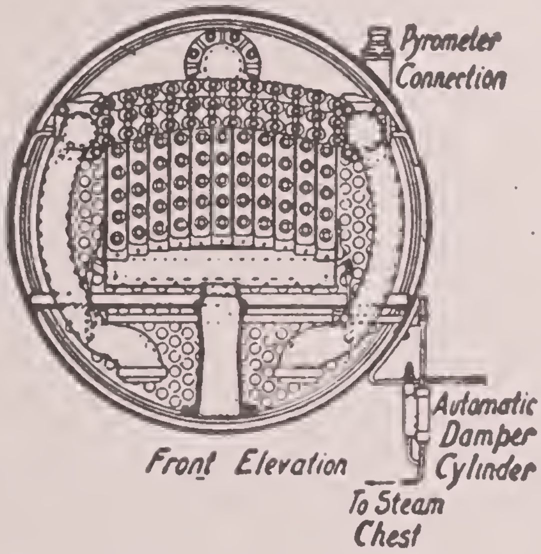


Fig. 113. Schenectady Superheater.

The first new feature of construction is in the T-pipe, the regular conventional T-pipe being replaced by one of special design, shown in Figs. 112, 113 and 115; it will be seen that this T-pipe is subdivided into two compartments by a horizontal partition, and that it extends nearly across the smokebox; steam entering the T-pipe from the dry pipe is admitted to the upper compartment only. To the front side of the T-pipe are attached eleven header castings, the joint being made with copper wire gasket, as in the steam chest practice; each header casting is also divided into two compartments, but in this case by a vertical partition; five pipes or flues of 1 1-16-inch outside diameter are inserted through holes (subsequently closed by plugs) in the front wall of each header casting, these 1 1-16-inch tubes having been expanded into special plugs, are firmly screwed into the vertical partition wall; these five 1 1-16-inch tubes are inclosed by five 1¾-inch tubes, which are expanded into the rear wall of the header casting in the usual way; each nest of two tubes (one 1 1-16-inch and one 1¾-inch) is encased by a regular 3-inch boiler tube, which is expanded into the front and back tube sheets as usual; the back end of each 1 1-16-inch tube is left open; the back end of each 1¾-inch tube is closed; the back ends of the two tubes being located at a point about 36″ forward from the back flue sheet. The detail arrangement and grouping of the three flues is shown by Fig. 114. The back end of the 1¾″ tube is closed by welding, and the tail is formed in such a manner as to support this tube in the upper part of the 3″ tube, thus leaving a clear space below. Fig. 112 shows that the 1 1-16″ tubes are concentric with the 1¾″ tubes at their ends, but the fact is, the 1 1-16″ tube is allowed to drop to rest on the bottom of the 1¾″ tube, as shown by Fig. 114.

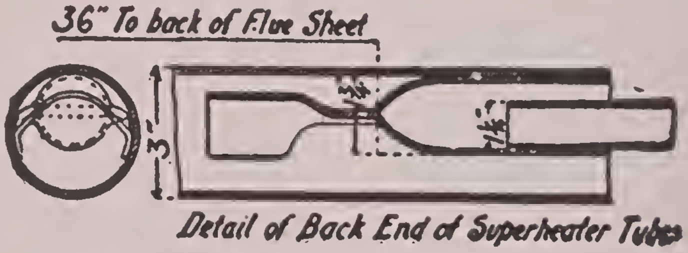

36″ To back of Flue Sheet
3″
Detail of Back End of Superheater Tubes

Fig. 114. Schenectady Superheater.

Steam from the dry pipe enters the upper compartment of the T-pipe and thence enters the forward compartments of each of the eleven header castings, thence passes back through each of the fifty-five 1 1-16" tubes, thence forward through the annular spaces between the 1 1-16" tubes and the 1¾" tubes to the rear compartments of each of the eleven header castings, thence into the lower compartments of the T-pipe, thence by the right and left steam pipes to the cylinders.

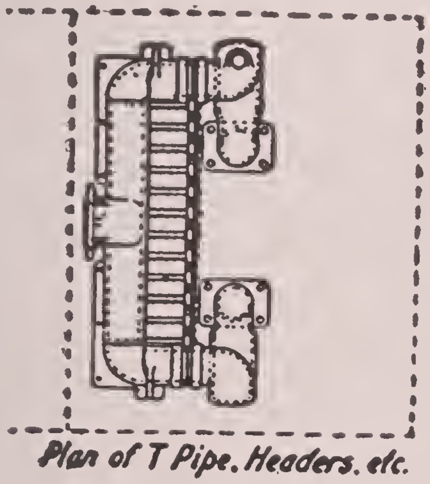


Fig. 115.

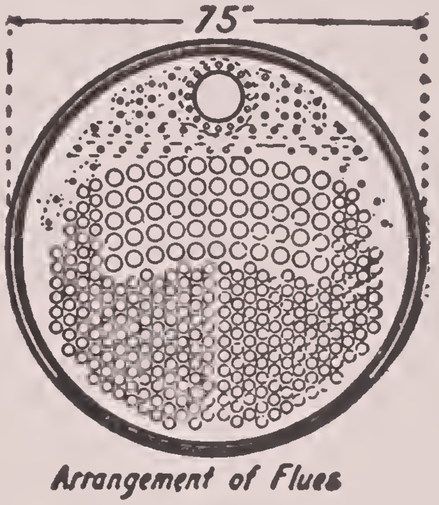


Fig. 116.

Schenectady Superheater.

In passing forward through the 1¾" tubes, the steam is superheated by the smoke box gases, and products of combustion passing through the three-inch tubes.

In this design fifty-five 3" tubes are inserted in the upper part of the flue sheets, thus displacing as many of the regular small tubes as would occupy the same space. Fig. 116 shows the arrangement of flues.

The arrangement of dampers for protecting the superheater tubes from excessive heat when steam is not passing through is shown in Figs. 112 and 113. That portion of the smoke box below the T-pipe, and back of the header casting is completely inclosed by metal plates. The lower part of this inclosed box is provided with an automatic damper, the action of which is as follows: when the throttle is opened, and steam is admitted to the steam chests, the piston of the automatic damper cylinder shown in Fig. 113 is forced upwards and the damper is held open, but when the throttle is closed, the vertical spring immediately back of the automatic damper cylinder (and concealed by it in Fig. 113), brings the damper to its closed position, thus preventing the heat from being drawn through the 3″ tubes when the engine is not working steam. There is a slight loss of heating surface, as the result of introducing 3″ tubes for the purpose of applying the superheater, but the claim is made that this loss is more than offset as regards economical results obtained by the superheating process.

Table 15 gives the loss per cent in heating surface of a regular engine, and one of the same class to which the superheater was applied.

TABLE 15.

Heating Surface. (Sq. Ft.)

	Regular engine.	Superheater engine.	Loss Per cent.
Fire box	175.0	175.0	0.0
Fire tubes	3248.1	2837.0	12.6
Arch pipes	23.0	23.0	0.0
Totals	3446.1	3035.0	11.9

It will be noted that the application of the superheater reduces the heating surface of the fire-box tubes by 12.6%, and reduces the total heating surface by 11.9%.

The actual superheating surface is 301 sq. ft., which is 10.6% of the fire tube heating surface, and 9.9% of the total heating surface of the superheater engine.

Readings taken from a pyrometer inserted in the left steam pipe (see Fig. 113), show that the average temperature is about 517 deg. F., the boiler pressure being 200 lbs. per sq. in.

The temperature of saturated steam at 200 lbs. per sq. in. is 387 deg. F. which shows a gain of 130 deg. accomplished by superheating.

Service tests made on a superheater locomotive operating on the Canadian Pacific Railway, showed a saving of 33% in fuel consumption as compared with a simple engine of the same class. This was on the ton mile basis.

The saving shown by the superheater engine, when compared with a similar compound engine was 16%. The piston rod packings are metallic, made of a special mixture, having a melting point of 1200 deg. F.

This is to guard against their being affected by excess heat in the cylinder.

When superheated steam is used, no chances dare be taken as regard cylinder lubrication, and forced feed of oil is used, instead of the usual gravity feed.

Although the maximum steam temperature is about 517 degrees, as stated, yet the constant temperature of the cylinder walls is probably something above the mean of 517 degrees, and the average temperature (perhaps 230 degrees) of the exhaust; it is therefore probable that the constant temperature of the cylinder walls, when steam is being used, is in the neighborhood of 385 degrees. which, however, is considerably higher than the corresponding temperature would be in the case of an engine not equipped with a superheater.

The particular forced feed lubricator which is used in this case is of German make, and embodies four reservoirs which are filled with oil before the beginning of the run, the oil being forced out of these reservoirs through connecting pipes to the cylinders by plungers, which receives a gradual but constant downward impulse by a screw motion, which is actuated by a system of levers connected with a return crank on one of the rear driving wheels; in this case two oil pipes are led forward from the lubricator to either side of the engine; one of each pair of oil pipes enters the live steam passage through the cylinder saddle, and the other is led directly into the cylinder at the middle of the stroke.

Casual consideration of this design might lead to the prediction that the upper or 3-inch tubes would be likely to choke up in service; but it should be remembered that the annular space in the lower part of these 3-inch tubes is quite free and unobstructed and can easily be reached and scoured by a steam jet from the firebox end. It should also be borne in mind that the upper flues in any locomotive are not nearly as likely to choke up as are the lower flues.

INJECTORS. The proper method of feeding water to a boiler while in operation under a high pressure, is a problem that demands the constant and earnest attention of the engineer, not only as a matter of personal safety, but the efficiency of the boiler depends in a large measure upon the manner in which the feed water enters the boiler. Theoretically the supply should just equal the demand at all times; that is to say, there should be a constant ingoing of water into the boiler during all the time that the fire is active, and the volume of water entering the boiler should exactly equal the volume of water that is being evaporated within the boiler. But these conditions are hardly possible in practice. Especially is this so in locomotive practice where the service differs so greatly from marine or stationary service. The judicious use of the injector on a locomotive is a subject that engineers and firemen should study to familiarize themselves with.

The importance of this matter is shown in the following extract from the report of a committee of the Traveling Engineers' Association: "It would hardly cut any figure how careful an engineer might be in the handling of his train, with the skill he uses in regulating speed or in the adjustment of the throttle and the reverse lever, if the water was not put into the boiler at the right time and the right place. In our experience we have known almost remarkable results to be brought about in an engine's fuel performance by explaining this matter to engineers who perhaps had not given it the thought that the subject deserves." It will be noticed that the committee emphasizes the importance of "putting the water into the boiler at the right time and the right place," if economy in fuel is to be attained, and this certainly is a worthy object for every locomotive engineer to have in view at all times.

Now as to the "right time" for putting water into a locomotive boiler: A good time to use the injector to advantage is while standing at a station. To this end, it is the practice of some engineers when approaching a stopping point, to allow the water level to drop below the normal point, thus utilizing the heat already stored in the water that is in the boiler to enable them to get into the station. When the throttle is closed for making the stop the injector may be started, and much of the heat that would otherwise be wasted at the pop valve will be utilized in forcing a new supply of water into the boiler. Another "right" time and place to use the injector is just after passing the summit of a long hill, when the throttle can be eased off. This will prevent the pop from rising so freely on the down grade, and thus another source of economy will be taken advantage of. There are many other "right" times and places for using the injector, that an observant and careful engineer will, by a little thinking, be enabled to figure out for himself. Much, of course, depends upon the kind of an injector a man has on his engine. If it has a wide range of capacities, and can be throttled so as to feed a very small jet without breaking, it may be used almost continuously, especially if the track is straight, and there are not very many heavy grades. The modern injector, as it is furnished at the present time by the leading manufacturers, approaches very nearly to being a perfect boiler feeder for locomotives. Ever since the time of the invention of the injector in 1858 by that eminent French engineer Henri Giffard, and its introduction into this country in 1860 by Wm. Sellers & Co., of Philadelphia, it has been constantly improved upon, and developed by various inventors and manufacturers, and it is to-day, without doubt, the most simple, the most economical, and the best device for feeding water into locomotive boilers. As a short study of the philosophy of the action of the injector is not only useful, but should be interesting to engineers and firemen, a space will be devoted to this subject. The leading types of injectors and inspirators will also be described and illustrated.

*How an Injector Works.** How can an injector lift and force large volumes of water into the boiler, against the same or even higher pressure than that of the steam?"

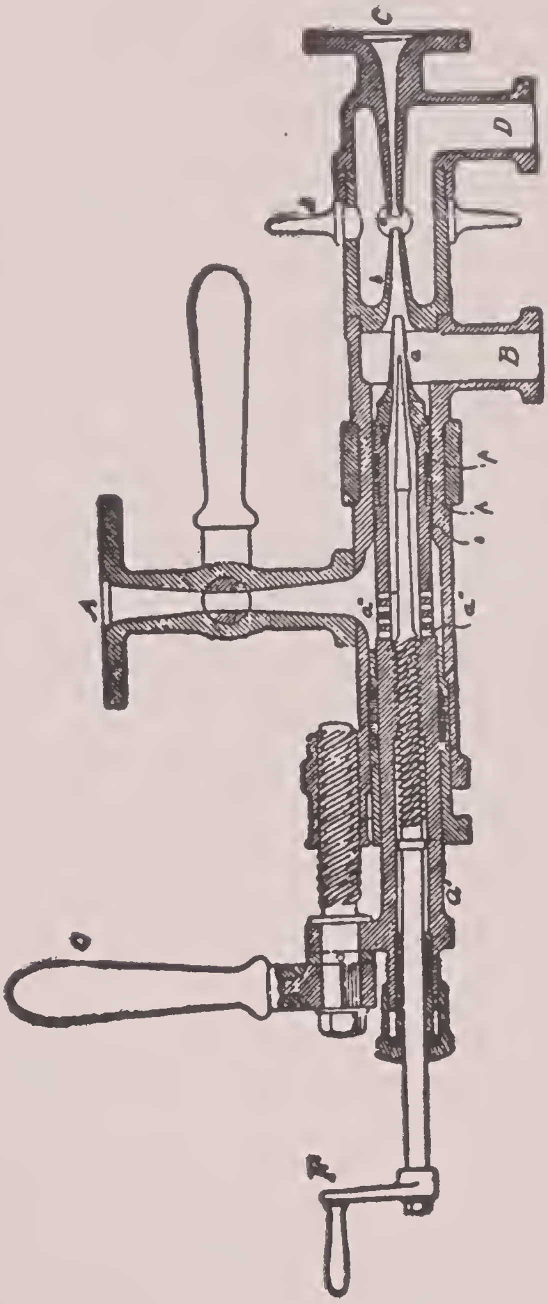


Fig. 117. Original Form of The Giffard Injector.

"An injector works because the steam imparts sufficient velocity to the water to overcome the pressure of the boiler."

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*Stricland L. Kneass, C. E., from Sellers' Hand-Book of Injectors.

This is a statement of fact; to explain the action, we will take up the important parts of the question separately.

Why should an injector work? Let us assume that the boiler pressure is 180 pounds—that is to say, every square inch of the sheets, top and bottom, receives an internal pressure of 180 pounds. If the thermometer is placed inside, it is found that both the water and the steam are at the same temperature, 379 deg. But the steam contains more heat than the water, because after water is heated, more coal must be burned to break up the drops of water to change them into steam; this heat is stored in the steam and represents work done by the burning of the coal. Steam not only exerts a pressure of 180 pounds per square inch, but also can expand eight to twenty-six times its original volume, depending upon whether it exhausts into the air or into a partial vacuum; water under the same pressure would be discharged in a solid jet and without expansion. Either steam or water can be used in the cylinder of an engine or to drive the vanes of a steam or water turbine, but one pound of steam is capable of much more work than one pound-weight of water, on account of the heat which has been used to change it into steam. This is easily seen by comparing the velocities of discharge from a steam nozzle and a water nozzle under 180 pounds pressure; steam would expand while issuing, reaching at the end of the nozzle a velocity of about 3,600 feet per second, while the water, having no expansion, would have a velocity of only 164 feet per second, about 1/22 of that of the steam. The same weight of steam discharging per second would therefore have vastly more power for doing work than the water jet.

If a steam or water jet comes in contact with a body in front of it, the tendency is to drive the body forward. The force which tends to move the body is called "momentum," and is equal to the weight of water or steam discharged by the jet in one second, mutiplied by its velocity per second. If 1 pound of both the water and the steam are discharged per second, the "momentum" of the steam jet is 3,600; because 1 multiplied by 3,600 =3,600; the momentum of the water jet is 164. If the water jet discharged about twenty-two pounds per second, its momentum would be the same as that of the steam, because 22 multiplied by 164 is nearly 3,600. The two jets are discharged under the same pressure, but the steam has twenty-two times as much "momentum" or force as the water jet; it could, therefore, easily enter a boiler at 180 pounds pressure if we could reduce it to the size of the hole of the water nozzle.

How ought an injector to work? Here a practical difficulty is reached. A steam jet 6 in. from the nozzle is much larger than at the opening, and it would appear almost impossible to make it enter a smaller tube. Even at the narrowest part of the nozzle it is more than sixteen times larger in diameter than a water jet discharging the same weight per second; therefore, if the steam is changed to water without reducing its velocity, it would pass through a hole one-sixteenth the diameter of the "steam nozzle" at a velocity of 3,600 feet per second. The simplest and best way to reduce its size is to condense it, and to use water for this purpose, especially as water is needed in the boiler. To condense the steam and utilize its velocity, the water must be brought into close contact with it, without interfering with the discharges one pound per second at 3.600 feet velocity, the momentum of the steam is 1 multiplied by 3,600, or 3,600. If the vacuum caused by the condensation of the steam lifts and draws into the combining tube ten pounds of water per second at a velocity of forty feet, its momentum is 400; and that of the combined jet is 3,600 added to 400, or 4,000. The weight of the combined jet is eleven pounds, and at the time of entering the delivery tube its velocity ought to be equal to 4,000 divided by 11, or 366 feet per second; but as the water and the steam do not meet in precisely the line of discharge there is a loss of momentum, and the velocity in the delivery tube is only 198 feet per second. But the jet only needs a velocity of 164 feet to enter the boiler or tank carrying 180 pounds pressure, therefore the actual jet in the delivery tube is able to overcome a pressure of 206 pounds per square inch, or twenty-six pounds above that of the steam, because the velocity of a jet of water under a head or pressure of 206 pounds would be 198 feet per second. This excess is more than sufficient to overcome the friction of the delivery piping and the resistance of the main check valve. Therefore:

"The action of the injector is due to the high velocity with which a jet of steam strikes the water entering the combining tube, imparting to it its momentum and forming with it during condensation a continuous jet of smaller diameter, having sufficient velocity to overcome the pressure of the boiler."

THE SELLERS IMPROVED SELF-ACTING INJECTOR. *Description.* This injector is simply constructed and contains few operating parts. The lever is used in starting only, and the water valve for regulation of the delivery. It is self-adjusting, with fixed nozzle, and restarts automatically. All the valve seats that may need refacing can be removed; the body is not subject to wear and will last a lifetime.

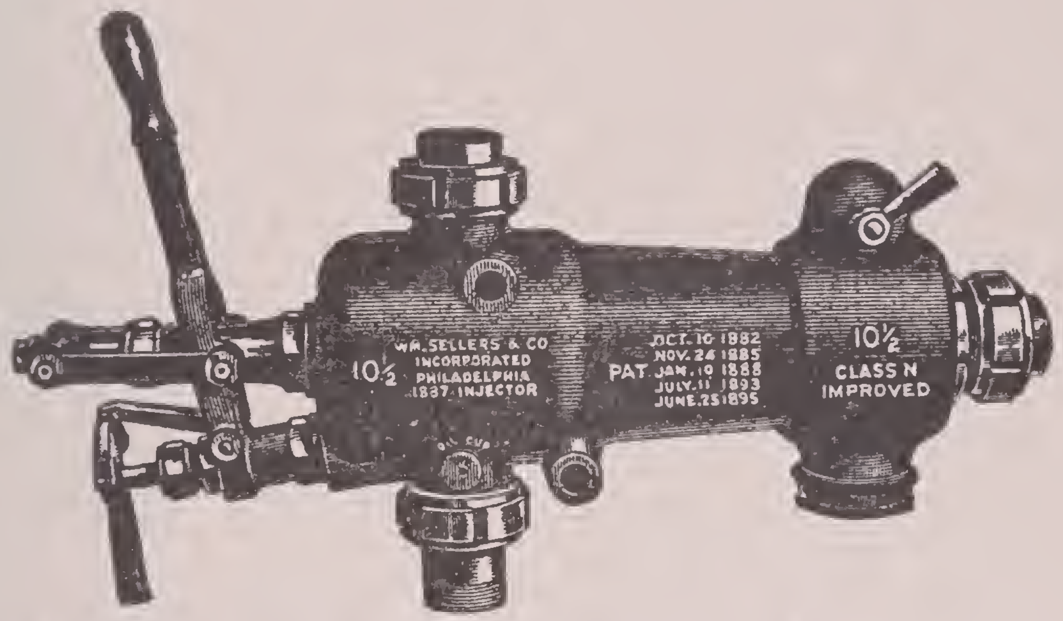

Fig. 118. The Self-Acting Injector, Class N Improved P. R. R. Standard.

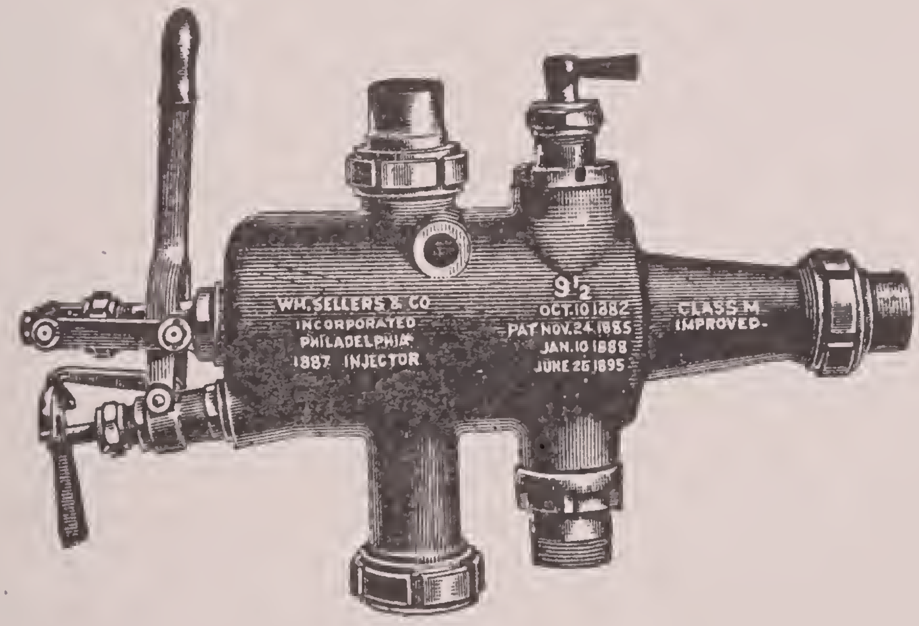

Fig. 119. The Self-Acting Injector, Class M Improved.

The action is as follows: Steam from the boiler is admitted to the lifting nozzle by drawing the starting lever (33) about one inch, without withdrawing the plug on the end of the spindle (7) from the central part of the steam nozzle (3). Steam then passes through the small diagonal-drilled holes and discharges by the outside nozzle, through the upper part of the combining tube (2) and into the overflow chamber, lifts the overflow valve (30), and issues from the waste pipe (29). When water is lifted the starting lever (33) is drawn back, opening the forcing steam nozzle (3), and the full supply of steam discharges into the combining tube, forcing the water through the delivery tube into the boiler pipe.

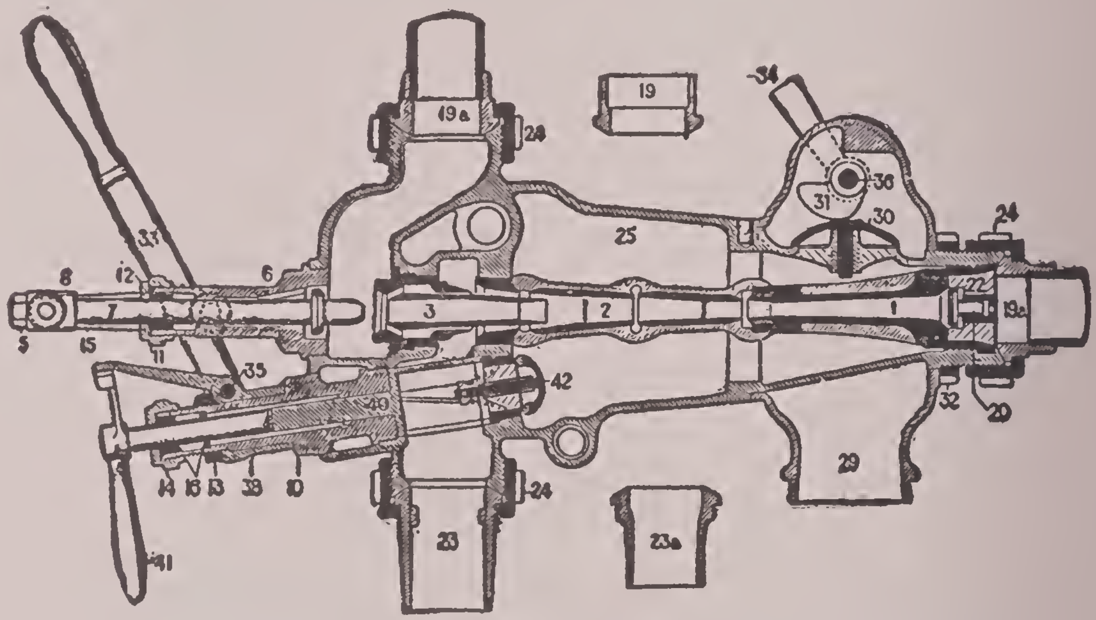

Fig. 120. The Self-Acting Injector, Class N Improved.
P. R. R. Standard. Sellers Standard Form.

At high steam pressure there is a tendency in all injectors having an overflow to produce a vacuum in the chamber (25). In the Improved Self-Acting Injector this is utilized to draw an additional supply of water into the combining tube by opening the inlet valve (42); the water is forced by the jet into the boiler, increasing the capacity about 20 per cent.

The water-regulating valve (40) is used only to adjust the capacity to suit the needs of the boiler. The range is unusually large.

The cam lever (34) is turned toward the steam pipe to prevent the opening of the overflow valve when it is desired to use the injector as a heater or to clean the strainer. The joint between the body (25) and the waste-pipe (29) is not subject to other pressure than that due to the discharging steam and water during starting; the metal faces should be kept clean and the retaining nut (32) screwed up tight.

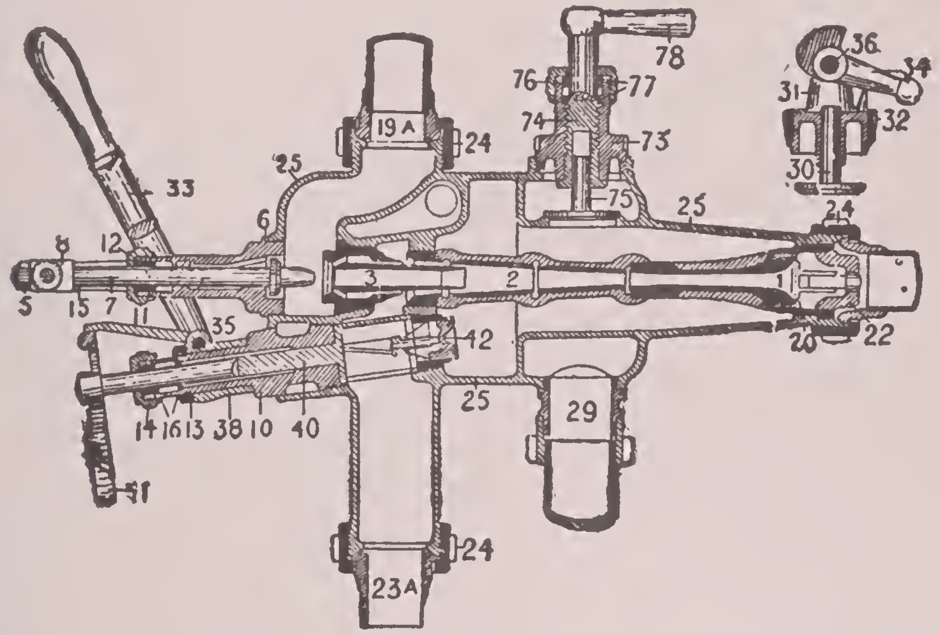

Fig. 121. Self-Acting Injector, Class M Improved—Special Form, Interchangeable with Monitor, Ohio, Etc.

To tighten up the gland of the steam spindle, push in the starting lever (33) to end of stroke, remove the little nut (5) and draw back the lever (33). This frees the crosshead (8) and links (15), which can be swung out of the way, and the follower (12) tightened on the packing to make the gland steam-tight.

The Improved Self-Acting Injector is specially adapted to railroad service, as its efficient, positive action and wide range of capacities at 200 pounds steam render its application to high-pressure locomotive boilers very advantageous. It will work from the highest steam pressures used on locomotives down to 35 pounds steam without adjustment and without wasting at the overflow, and by regulating the water-supply valve on the injector it can be operated at 15 pounds. As it restarts instantly under all conditions of service, it can always be depended upon to force all the water into the boiler, so that the engineer can give his whole attention to his other duties.

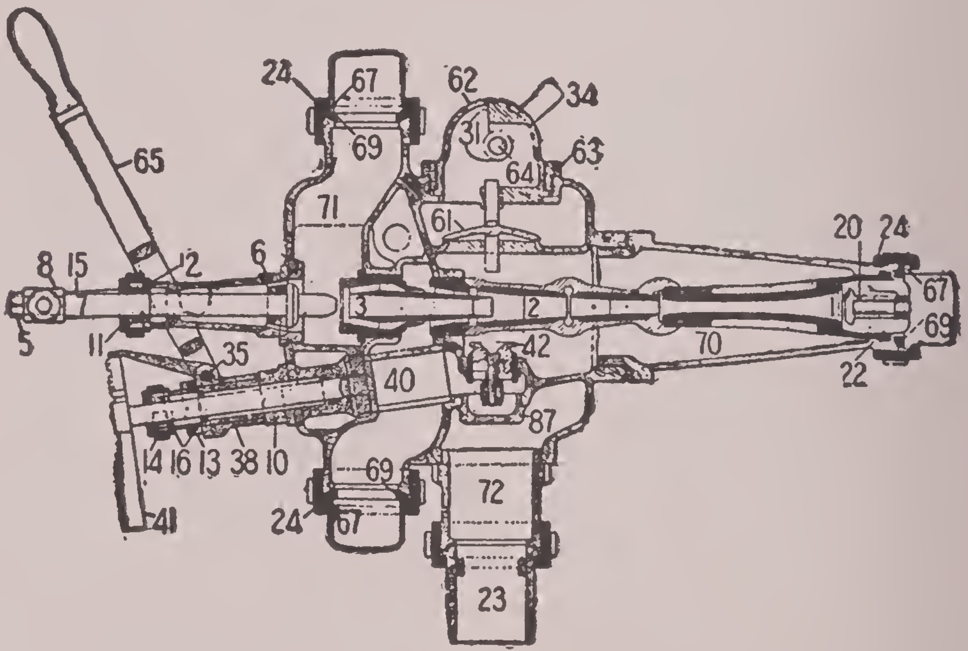

Fig. 122. Self-Acting Injector, Class P, Special 10½ and 11½ Only.

Sizes of Injectors for Locomotives.* In determining the size of injector required for locomotives, the size of the cylinder is usually taken as the standard, although the diameter of the boiler and the kind of service for which the locomotive is intended has a modifying influence.

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*From "Practice and Theory of the Injector," Wiley & Sons, New York.

TABLE 16.

Diam. of Cyl., inches	Size of Injector	Diam. of Cyl., inches	Size of Injector	Diam. of Cyl., inches	Size of Injector	Diam. of Cyl., inches	Size of Injector
9	$4\frac{3}{10}$	13	$5\frac{4}{10}$	17	$7\frac{1}{2}$	21	$9\frac{1}{2}$†
10	$4\frac{8}{10}$	14	$6\frac{1}{2}$	18	$8\frac{1}{2}$	22	$10\frac{1}{2}$
11	$5\frac{1}{10}$	15	$6\frac{1}{2}$	19	$8\frac{1}{2}$†	23	$10\frac{1}{2}$
12	$5\frac{4}{10}$	16	$7\frac{1}{2}$	20	$9\frac{1}{2}$	24	$11\frac{1}{2}$
						25	$11\frac{1}{2}$
						26	$12\frac{6}{10}$

† Use next size larger with specially large boiler.

TABLE 17.

IMPROVED SELF-ACTING INJECTOR

MAXIMUM AND MINIMUM CAPACITIES, ALL CLASSES

Gallons per Hour—5 Feet Lift. (7½ Gallons = 1 Cubic Foot.)

Size	60 Lbs. Steam		120 Lbs. Steam		180 Lbs. Steam		200 Lbs. Steam	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
‡$4\frac{3}{10}$	427	158	562	208	517	345	500	350
$5\frac{4}{10}$	667	247	907	340	1027	395	1035	455
$6\frac{1}{2}$	967	358	1320	489	1492	568	1516	667
$7\frac{1}{2}$	1290	477	1755	650	1987	757	2010	885
$8\frac{1}{2}$	1657	613	2257	835	2550	970	2587	1138
$9\frac{1}{2}$	2070	766	2820	1044	3150	1197	3187	1402
$10\frac{1}{2}$	2535	938	3450	1280	3900	1482	3952	1740
$11\frac{1}{2}$	3037	1124	4132	1530	4672	1775	4725	2079
$12\frac{6}{10}$	3650	1351	4968	1847	5616	2134	5700	2450

‡ Class N. Imp. not made $4\frac{3}{10}$ size; only supplied in Classes L, M, and N.

THINGS TO BE REMEMBERED. WITH LOCOMOTIVES CARRYING HIGH STEAM PRESSURE (180 to 225 POUNDS). Set the injector just above the top water level of the tank. At 8 feet lift, 200 pounds, the capacity is about 10 per cent less than the list.

Cold water is best for the injector. Hot water reduces the life and efficiency. At 120 deg. the capacity is about one-third below list given in the table. The range of capacities is reduced and no injector lifts as promptly.

Use large suction pipe and tank valve connections. If the diameter is increased one size, the gain in capacity is from 5 to 10 per cent.

Use large strainer with small holes. Small strainers require frequent cleaning. If the holes are large, cinders and coal pass through and wear the tubes. If the strainer is too small, the injector does not give full capacity. Be sure that the gasket between hose and suction pipe is not squeezed so as to close opening.

Suction pipe must be absolutely tight. Any leak of air reduces the capacity and makes the overflow valve jump.

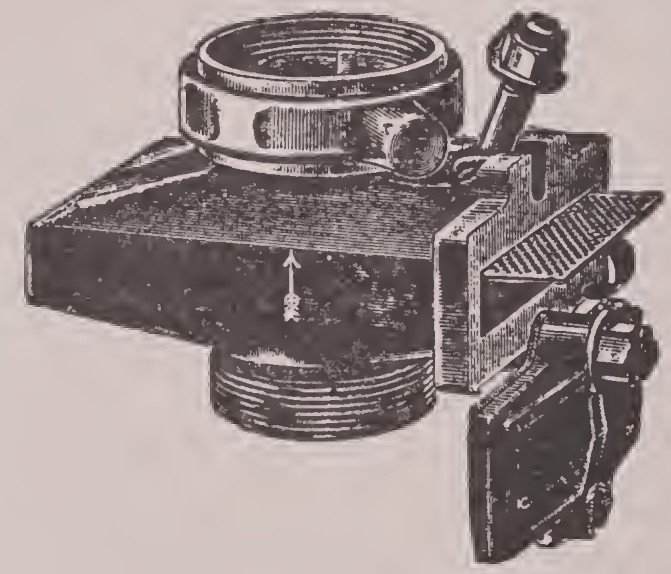


Fig. 123. Locomotive Feed-Water Strainer for Right-or Left-Hand Side of Engine.

Delivery pipe and main check valve must be of ample area. If an injector gives high back pressure, it is using too much steam. If the delivery opening is too small, the power of the injector is wasted in increased friction in the pipes.

Take good care of the injector. Keep all glands steam-tight, and watch carefully for leaks in the suction pipe. Do not force the steam valve hard against its seat; close the valve gently. Start the injector in the same way; at very high pressure the delivery pipe is liable to burst if the lever starting valve is jerked open. Keep the injector clean and report at once if not working properly. Do not run with the water-regulating valve wide open all the time.

List of Parts, Self-Acting Injector,

Class N Improved

1. Delivery Tube.
2. Combining Tube.
3. Steam Nozzle.
5. Spindle Nut.
6. Steam Stuffing Box.
7. Spindle.
8. Cross-Head.
10. Water Stuffing Box.
11. Follower.
12. Packing Ring.
13. Lock Nut.
14. Follower for No. 10.
15. Links.
16. Packing Ring.
19. Plain. {Rings for Copper Pipe.
19a. Reduc. {Rings for Copper Pipe.
20. Check Valve.
22. Guide for No. 20.
23. Plain {Unions for Iron Pipes.
23a. Reduc. {Unions for Iron Pipes.
24. Coupling Nuts.
25. Injector Body.
27. Wrench.
29. Waste Pipe.
30. Waste Valve.
31. Waste Valve Cam.
32. Jam Nut for No. 29.
33. Starting Lever.
34. Cam Lever.
35. Pin, Nos. 38 and 33.
36. Cam Shaft.
37. Washer on 36.
38. Collar and Index.
39. Funnel.
40. Plug Water Valve.
41. Regulating Handle.
42. Inlet Valve.
57. Closed Overflow Connection.

List of Parts, Self-Acting Injector,

Class M Improved

1. Delivery Tube.
2. Combining Tube.
3. Steam Nozzles.
5. Spindle Nut.
6. Steam Stuffing Box.
7. Spindle.
8. Cross-Head.
10. Water Stuffing Box.
11. Follower.
12. Packing Ring.
13. Lock Nut.
14. Follower for No. 10.
15. Links.
16. Packing Ring.
19. Plain } Rings for Copper Pipe.
19a. Reduc. }
20. Check Valve.
22. Guide for No. 20.
23. Plain } Unions for Iron Pipes.
23a. Reduc. }
24. Coupling Nut.
25. Injector Body.
27. Wrench.
29. Waste Pipe.
30. Waste Valve.
31. Guide for No. 30.
32. Jam Nut for 31.
33. Starting Lever.
34. Cam Lever.
35. Pin, Nos. 38 and 33.
36. Pin through 31 and 34.
38. Collar and Index.
39. Funnel.
40. Plug Water Valve.
41. Regulating Handle.
42. Inlet Valve.
57. Closed Overflow Connection.
73. Guide for Overflow Valve 75.
74. Heater Stem.
75. Overflow Valve.
76. Follower.
77. Pack Ring in 73.
78. Heater Lever.

THE SELLERS' SELF-ACTING INJECTOR. CLASS P—SIZES 10½ AND 11½. This is a special form of body, designed to be applied to the back-head of the locomotive boiler, with the starting lever and water regulating valve placed directly over the brake valve and within convenient reach when the engineer is seated. The coupling nuts and sizes of the pipe are Pennsylvania Railroad (Sellers') Standard, but the branches are located so as to avoid the fire-door and boiler attachments.

HINTS TO BE READ BEFORE CONNECTING THE INJECTOR.

1. Blow out all pipes carefully with steam before attaching the injector, tapping the pipe with a hammer in order to loosen all the scale.

2. When drip pipe is attached close to overflow of injector, it must be same size as given in table.

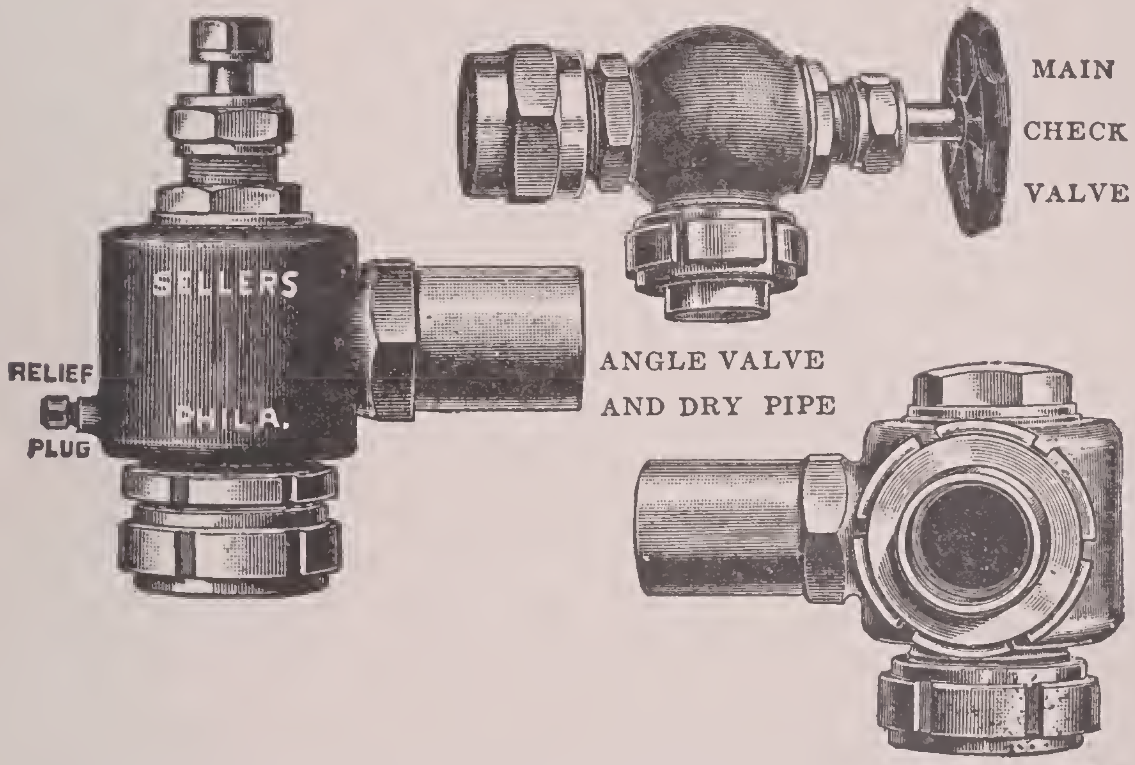


Fig. 124. Combined Stop and Main Check Valve; by Closing the Stop Valve, the Check Valve and Seat Can Be Removed Without Blowing Off Boiler. Screw or Flanged.

3. Always use a dry pipe attachment to insure perfectly dry steam.

4. The diameter of the strainer should be large enough to give an ample supply of water even when some of the holes are choked.

5. Keep all valves steam-tight; all leaks tend to increase rapidly, owing to the velocity with which steam passes through the smallest opening.

6. Keep the steam pipe and chamber free from dirt and chips from the threads on the pipes, and the steam nozzles perfectly clean. The steam nozzle is the life of an injector, and should be maintained in best condition. If the injector is new and the lifting nozzle should fill up, remove from body as described.

7. When grinding the steam valve, place a rubber washer over the holes leading to the lifting nozzle to prevent the sand from working into the lifting jet; this washer should, of course, be provided with a hole large enough to admit the plug on the end of the spindle; then screw the steam stuffing box rather tightly against its shoulder to insure its proper alignment. Keep the steam valve perfectly tight.

8. To remove lime and scale, immerse the tubes or the whole injector in a bath composed of ten parts of water to one part muriatic acid. Remove as soon as scale is dissolved.

Emergency Methods of handling the improved self-acting injector (Locomotive Firemen's Magazine). The improved self-acting injector in good working order is the most satisfactory boiler feeder that can be used, and fully deserves the confidence placed in it by careful enginemen. But there are times when even the best injector refuses to work. It may not be the fault of the injector itself; in fact, it seldom is to blame. Sometimes the trouble is due to careless handling, to the leaky condition of the steam valves, joints of the suction pipe and hose coupling; to cinders and dirt in the tank; and under such conditions many an injector is struggling, which not only reduces the efficiency and length of service, but finally prevents it from delivering water to the boiler.

It is of course difficult to do much in the way of repair to an injector when out on the road; even the pipe-coupling wrench is apt to be missing, and few tool boxes have wrenches for the removal of the tubes. A special feature of the self-acting injector is that the combining and delivery tubes can be removed with ordinary tools, but when it is necessary to take an injector apart the leakage from the steam and main check valves makes the work very disagreeable; but when an injector does not work it is something more than aggravating, it is often serious, especially if the left-hand injector has not been used for some time and also refuses to start. Then is the time for quick thinking and quick acting.

Suppose that an injector suddenly stops working. Probably the tubes, hose, suction pipe or strainer are stopped up. The last two can probably be cleared out by closing the cam over the overflow valve and drawing the starting lever quickly; if the hose lining has become loose it will let the steam flow back and close up again as soon as the injector is started, disabling this injector until a short nipple or coiled wire can be forced up the hose or a new hose obtained. If the next station cannot be reached before water is needed the left-hand injector must be made to work, unless the train is stopped and the injector and pipes thoroughly examined. Treat the left-hand injector exactly as the right. Open the tank valve and draw the injector starting lever; if the water is lifted, but will not enter the boiler, set the lazy cock at half capacity and tap the main check valve on cap with hammer to loosen it in its guide; at half capacity, because at that point the injector gives a higher back pressure than with the lazy cock wide open. This will probably be effective.

To Remove Tubes. The sectional views show very clearly how the tubes are held in the body. Uncouple the feed pipe from the injector and swing it out of the way; place a monkey wrench on the guide (22) for the line check (20) and unscrew; in some of the older patterns of injector it may be necessary to insert an old file or flat piece of iron, or perhaps two pieces in opposite openings; at any rate, it can be removed quite easily unless the seats are heavily lined up. This draws out the combining (2) and delivery (3) tubes, which can be separated and carefully examined inside; here is where the trouble will usually be found, and the impediment must be taken out without bruising the surface or bending the tubes. When the parts are replaced, test before recoupling the feed pipe. No steam should issue from suction branch.

Frequently the cause of stoppage is the absence of a strainer in the tank or suction pipe, or due to the fact that the holes in the straining plate are too large. An admirable arrangement of fixed strainer is shown in Fig. 123 placed between the hose and the suction pipe.

Suppose that steam nozzles (piece 3) require cleaning. Stoppage of the lifting tube is usually gradual and is shown by a slow falling off in the working of the injector. These tubes are more difficult to remove unless a wrench to fit the hexagon is at hand. Sometimes a large iron chip or heavy piece of scale is carried into the nozzle (piece 3) by the steam, due to carelessness when cleaning the boiler, but this is of infrequent occurrence. If this happens it is better to make running repairs to the other injector and leave it for the men in special charge of injector repairs.

At times the main check valve does not seat and all efforts to close it prove unavailing; if the line check valve has been omitted during repair, the water from the boiler rushes back into the injector. With injectors having no lazy cock, the only method of preventing the burning of the crown sheet is to draw the fires; but with the self-acting close the overflow valve by means of the cam, then quickly shut the lazy cock. The check pipe and injector body will then carry full boiler pressure until the roundhouse is reached, when the fire can be drawn and the pressure blown off.

Leakage of air into the suction pipe is usually the cause for unsatisfactory working of the injector. Enginemen should be especially careful about this and always tighten the joints so that no air can enter; even a slight drip from any of the joints under the pressure of the water in the tank indicates a large enough opening to admit sufficient air to affect the working of the injector, especially when the water level in the tank is low. Another point is the tightness with which the cover of the manhole of the tank fits on its seat; if air does not enter freely upon the top of the water the capacity of the injector will be reduced, the effect being more marked at high steam pressures and long lift than under ordinary conditions.

Lime and salts contained in the supply water coat the surfaces of the tubes; the accumulation occurs slowly, destroying the restarting feature, the promptness of lifting, and reduces the capacity; this should be at once reported to the proper authorities.

Inlet Valve (42). When the improved injector is feeding, the overflow chamber—the part of the body between the water branch and the waste pipe—is filled with cold water; if it does not feel cold to the hand the inlet valve (42) is not open and working properly. This method of surrounding the tubes with cold water tends to prevent the formation of scale, and this pattern of

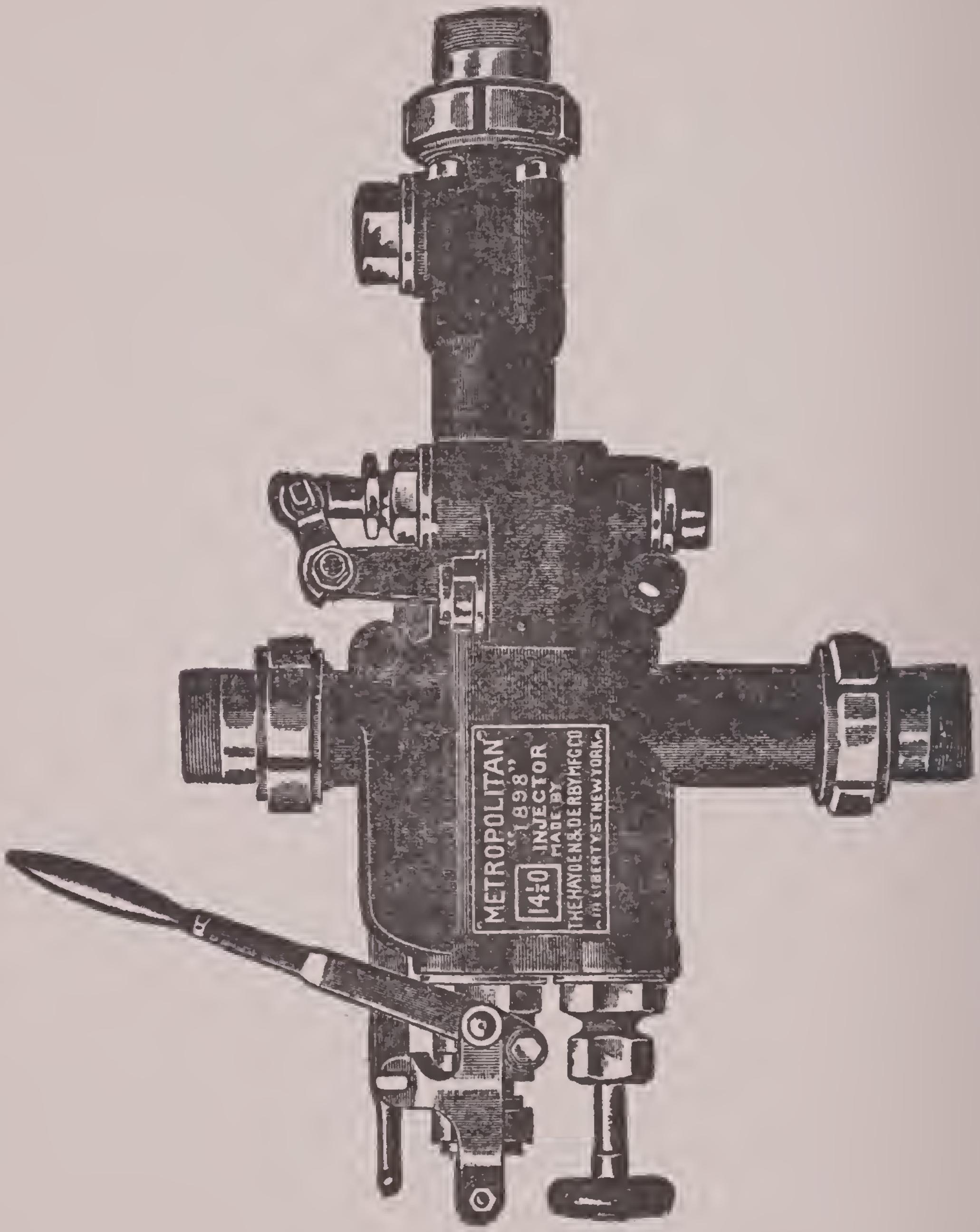


Fig. 125. Metropolitan "1898" Locomotive Injector.

injector gives longer service in districts where the supply water contains lime than those that do not contain this feature. Crude oil introduced into the steam or water pipe softens the scale and is often helpful. Bosses on both the water and the steam branches may be tapped for self-feeding oil cups, but all the joints should be tight.

Maintain the injector in good working order.

THE METROPOLITAN "1898" LOCOMOTIVE INJECTOR, Figs. 125 and 126, is a double-tube injector, composed of a lifting set of tubes which lifts the water and delivers it to the forcing set of tubes under pressure, which in turn forces the water into the boiler.

The lifting set of tubes acts as a governor to the forcing tubes, delivering the proper amount of water required for the condensation of the steam, thus enabling the injector to work without any adjustment under a great range of steam pressure, handle very hot water and admit of the capacity being regulated for light or heavy service under all conditions.

This injector will start with 30 to 35 lbs. steam pressure, and without any adjustment of any kind will work at all steam pressures up to 300 lbs. In fact, at all steam pressures and under all conditions its operation is the same. When working, all the water must be forced into the boiler. It is impossible for part or all the water to waste at the overflow should the steam pressure vary.

The injector is easily handled. The lever works very freely and can be handled without care, for there is no sensitiveness whatever in starting, as is the case with most injectors; consequently any one can operate it.

Regulation of capacity is an important, in fact indispensable feature of the perfect locomotive injector. With

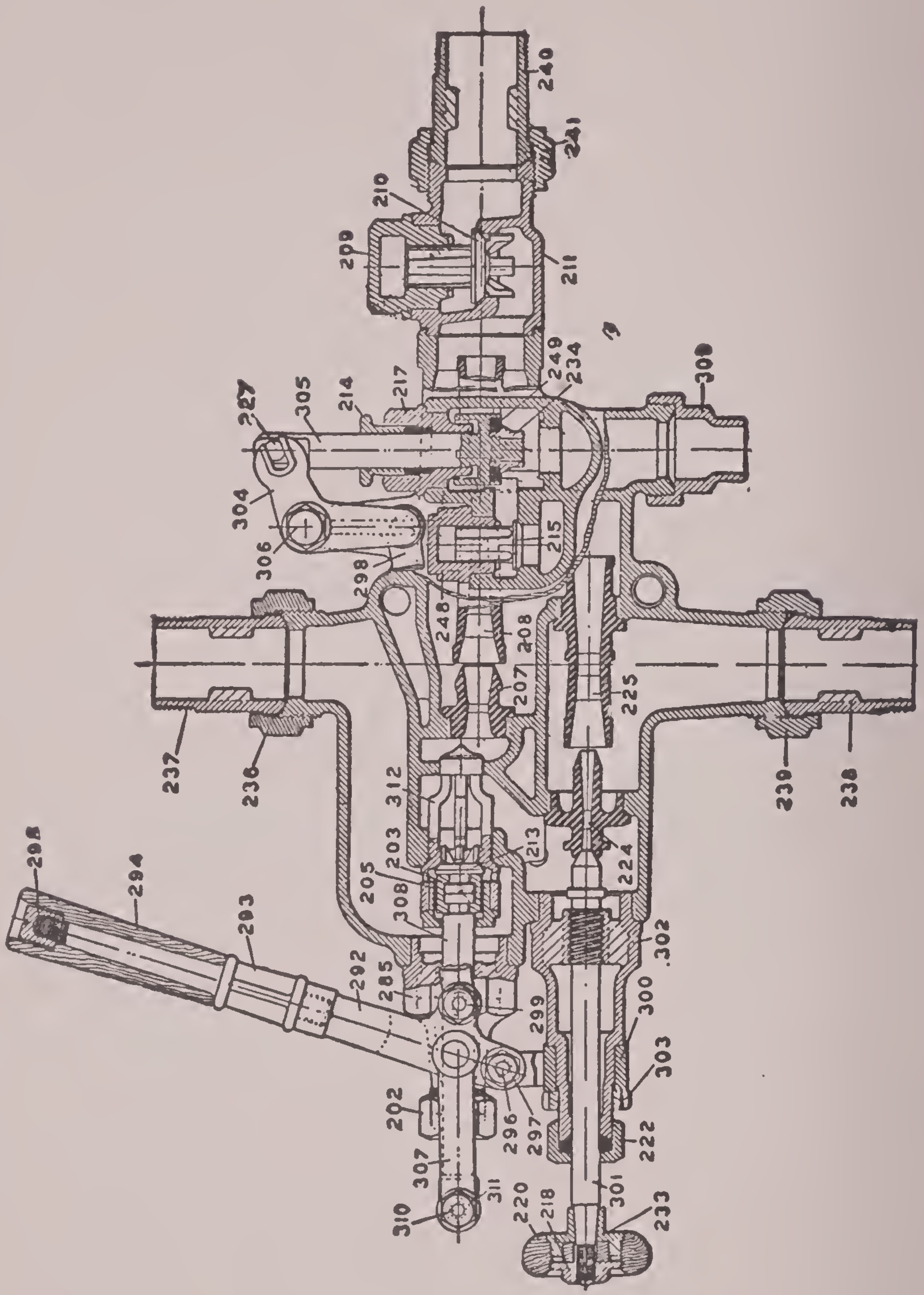


Fig. 126. Metropolitan "1898" Injector, Sectional View.

Metropolitan "1898" locomotive injectors the capacity can be regulated for light or heavy service under all steam pressures and with hot as well as with cold feed water. While most injectors will admit of the capacity being regulated with low steam pressures and cold feed water, this injector is the first that admits of a successful regulation with steam pressures up to and above 250 lbs. and with the feed water heated.

Model H Metropolitan "1898" locomotive injectors will interchange and fit the Monitor coupling connections. Model H injectors, sizes 5 and 6, have same size body and interchange. Sizes 8 and 9 have same size body and interchange. Sizes 11 and 12 have same size body and interchange.

The Model H and Model I types of these injectors differ solely in the pipe connections and the form of the main casing or shell. All the parts for each are the same for corresponding sizes.

Model I Metropolitan "1898" locomotive injectors will interchange and fit the Sellers coupling connections. Model I injectors, sizes 6 and 7, have the same size body and interchange.

The Metropolitan locomotive injector is manufactured by the Hayden and Derby Manufacturing Company of New York, who furnish the following directions for connecting and operating it.

Pipe Connections. The injector should be located inside the cab, so that it can be conveniently handled by the engineer.. It should be located with the overflow nozzle about 4 in. above the top of the tank. It is necessary that the steam pipe and the openings in the main steam valve should be as large or larger than the inside diameter of the sizes of copper pipe given in the list below, so that the injector will receive a full supply of dry steam. The openings in the goose neck and tank valve should not be smaller than the size of suction pipe called for in the list below.

TABLE 18.

Size	Capacity per Hour		Pipe Connections							
	Steam Pressures		Steam		Suction		Delivery		Overflow	
	160 Pounds	210 Pounds	Iron	Copper	Iron	Copper	Iron	Copper	Iron	Copper
5	1180 gals.	1210 gals.	1¼	1½	1¼	1½	1¼	1½	1¼	1½
6	1605 gals.	1647 gals.	1¼	1½	1¼	1½	1¼	1½	1¼	1½
7	2095 gals.	2151 gals.	1½	1¾	1½	1¾	1½	1¾	1½	1¾
8	2651 gals.	2723 gals.	2	2	2	2¼	2	2	1½	1¾
9	2954 gals.	3034 gals.	2	2	2	2¼	2	2	1½	1¾
9½	3274 gals.	3362 gals.	2	2	2	2¼	2	2	1½	1¾
10	3961 gals.	4068 gals.	2	2¼	2½	2¾	2	2¼	1½	1¾
11	4215 gals.	4450 gals.	2	2¼	2½	2¾	2	2¼	1½	1¾

Operation. To start the Metropolitan "1898" locomotive injector, the lever, part 292, Fig. 126, is drawn back, lifting the auxiliary steam valve, part 213, from its seat. This allows steam to flow through the lifting steam jet, part 224, into the lifting combining tube, part 225, thereby creating a vacuum in the suction chamber, causing the water to flow through the lifting combining tube, part 225, condensing the steam, then out through the overflow valve, part 215, and through the final overflow valve, part 234, through the overflow pipe to the atmosphere. A further movement of lever, part 292, closes the final overthrow valve thereby turning the water from the overflow into the boiler, thus opening the check valve, part 210. When the injector is working, the overflow valve is closed and held to its seat by pressure equal to the boiler pressure.

The capacity of the Metropolitan "1898" locomotive injector is regulated by increasing or decreasing the amount of steam to the lifting steam jet, part 224, by means of the regulating valve, part 301. When this valve is wide open, the lifting steam jet, part 224, receives a full amount of steam, which enables the lifting apparatus of the injector to lift the greatest quantity of water and deliver it to the forcing apparatus. When this regulating valve, part 301, is partially closed, it will partially close the opening into the lifting steam jet, part 224, decreasing the flow of steam, which will decrease the amount of water lifted by the lifting apparatus. This arrangement has been found to be far better than the old method of throttling the water supply. It enables the injector to run steadier when working at its minimum capacity and also enables the capacity to be reduced more.

To use the injector as a heater, lift the side links, part 286, by means of the small handle on same, and pull the links back until the pin, part 287, drops into the notch. This operation causes the final overflow to be closed and a small amount of steam can be admitted, enough to heat the injector. When it is desired to operate the injector after using it as a heater, the lever is simply pushed in, which will place the injector in positon to be operated.

If the injector breaks or will not start promptly, see if there is a leak in the suction connection. If the openings into the tank are too small, or the hose strainer clogged, or the hose kinked, or the hose lining is collapsed, the injector will not get a sufficient supply of water. If the injector will lift the water but will not deliver it into the boiler, see that the intermediate or line check valve, or the main boiler check valve are in proper working order, also examine the suction pipe for leaks. A leak in the suction pipe, while it may not prevent the injector from lifting, will prevent the water being forced into the boiler. If the main steam pipe or the main steam valve are not of sufficient size, or if there is a leak in the dry pipe, the injector will not receive a supply of steam sufficient to force the water into the boiler. If the overflow pipe is smaller than the overflow nozzle, there will be a back pressure, which will prevent the injector from lifting the water promptly. The overflow nozzle and overflow pipe should be kept free from lime or scale. This is very important.

Repairing. When the tubes become worn they should be renewed. The forcing tubes are removed by removing the check valve casing, part 211, by breaking the flanged joint. The lifting tubes are removed by removing the regulating center piece, part 302. Should the steam valves leak they should be re-ground. Overflow valve, part 215, must seat tightly. If this valve leaks, it will cause the hot water from the delivery chamber of the injector to be forced into the intermediate chamber and drawn into the combining tube, part 208, causing the injector to break. This is very important.

The final overflow valve has a soft disk, part 249. This disk is made soft so that in case the valve should close on to any hard substance, it will not injure the valve seat. These disks can be removed very easily and are very inexpensive.

Swing Intermediate or Line Check Valves (Hancock Pattern, Fig. 127). These check valves can be applied to any locomotive injector.

There are no wings or guides to become incrusted with scale or deposit while the valve is open, which would prevent its closing, and the liability therefore of damage or delay caused by the valve failing to close is obviated.

THE MONITOR INJECTOR. (Figs. 128-129, made by the Nathan Manufacturing Co., New York.) The proper position of this injector is in the cab above the level of the water in tender, convenient to engineer. Should the Monitor have to be placed outside, it must be provided with connecting rods extending into the cab. Steam should be taken from dome or highest part of boiler to insure best effects.

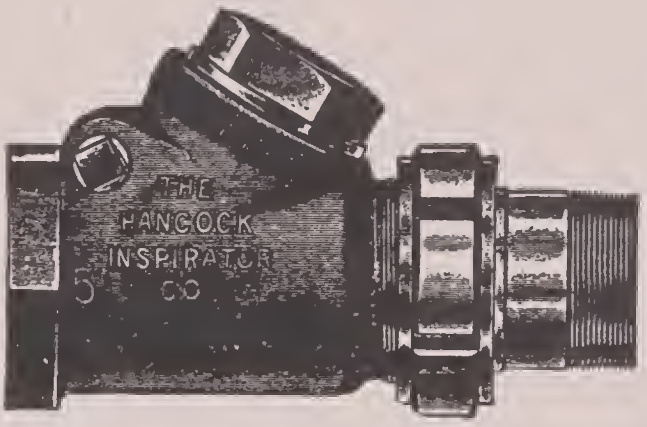


Fig. 127. Swing Intermediate Check Valves, Exterior View.

Its Range. It does not waste water at overflow by ordinary variation of working steam pressure, but steadily performs its duty, whether the water-valve is wide open or throttled down until almost shut.

Steadiness. It works steadily, whether the engine is running fast or slow; while reversing, applying brakes, and during ordinary stoppages. It is also capable of running heavy as well as light trains, the quantity of water needed being easily regulated by the water-valve attached.

Reliability. It is provided with an independent lifting jet, which enables the injector to start promptly at all times. This is a peculiar feature and very important, because it allows the injector to start as promptly after doing its duty as a heater cock, as at first.

Flanged Monitors. Since 1885 the body of the Monitor has been divided into two parts, which are firmly held together by a double flange securely bolted. This very convenient arrangement enables the interior parts to be taken out readily, for cleaning or renewal, when necessary, without injury to the injector.

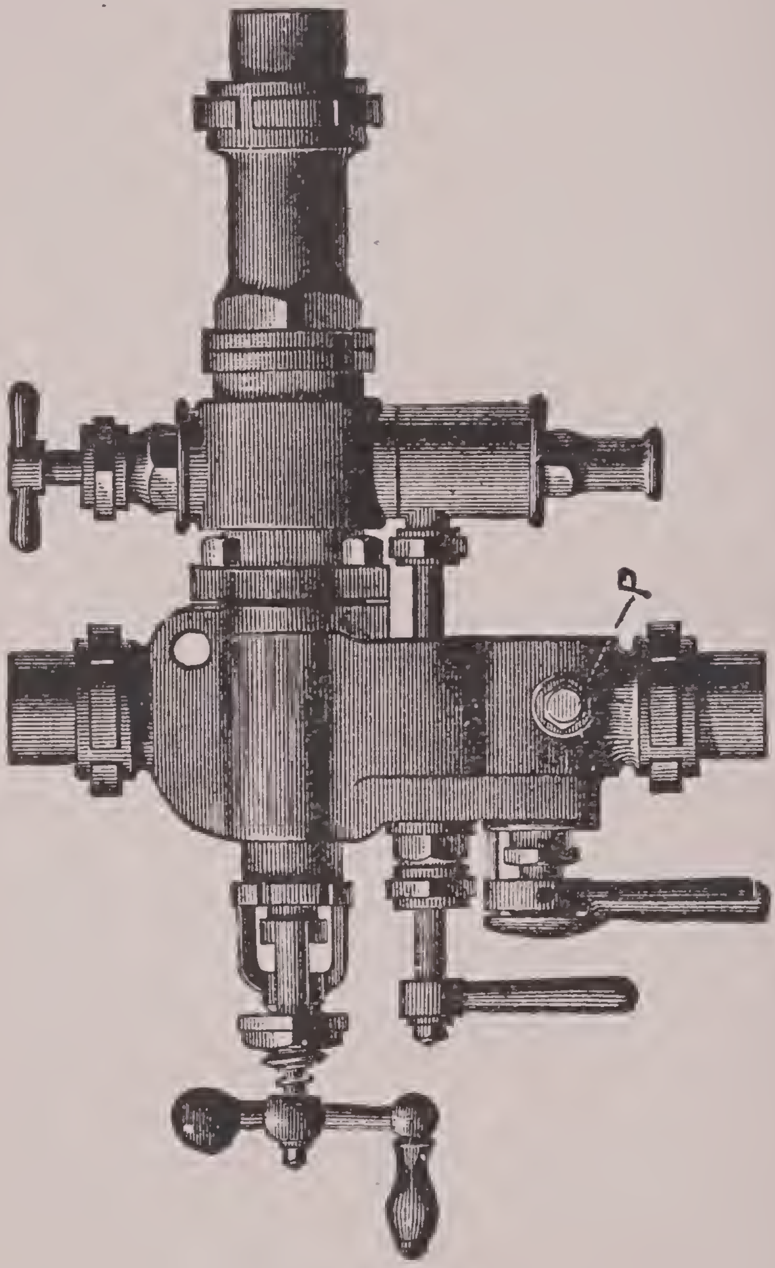


Fig. 128. The "Monitor," Exterior View.

Recent Improvements. The steam valve spindle is provided with an improved patent yoke stuffing box, which makes it possible to place the threaded part of the spindle outside the steam chamber, diminishing its wear. The packing can be adjusted and tightened by means of a large central nut, still preserving the simplicity and convenience of an ordinary stuffing box.

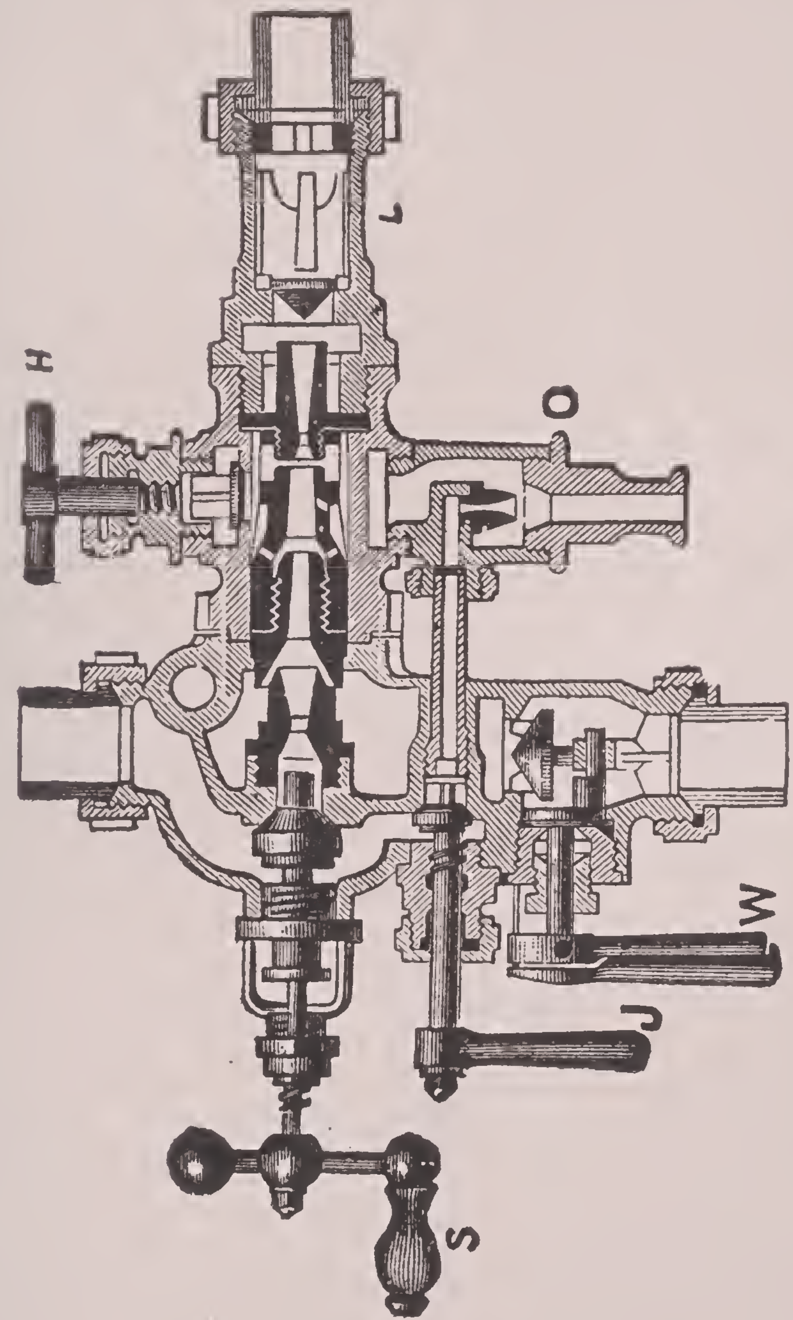


Fig. 129. The "Monitor"—Interior View.

The water valve has been provided with a double handle with index pin, which engages with notches, cut into the stuffing box cap, thereby keeping the water valve steady in any position against any jar or vibration of the engine.

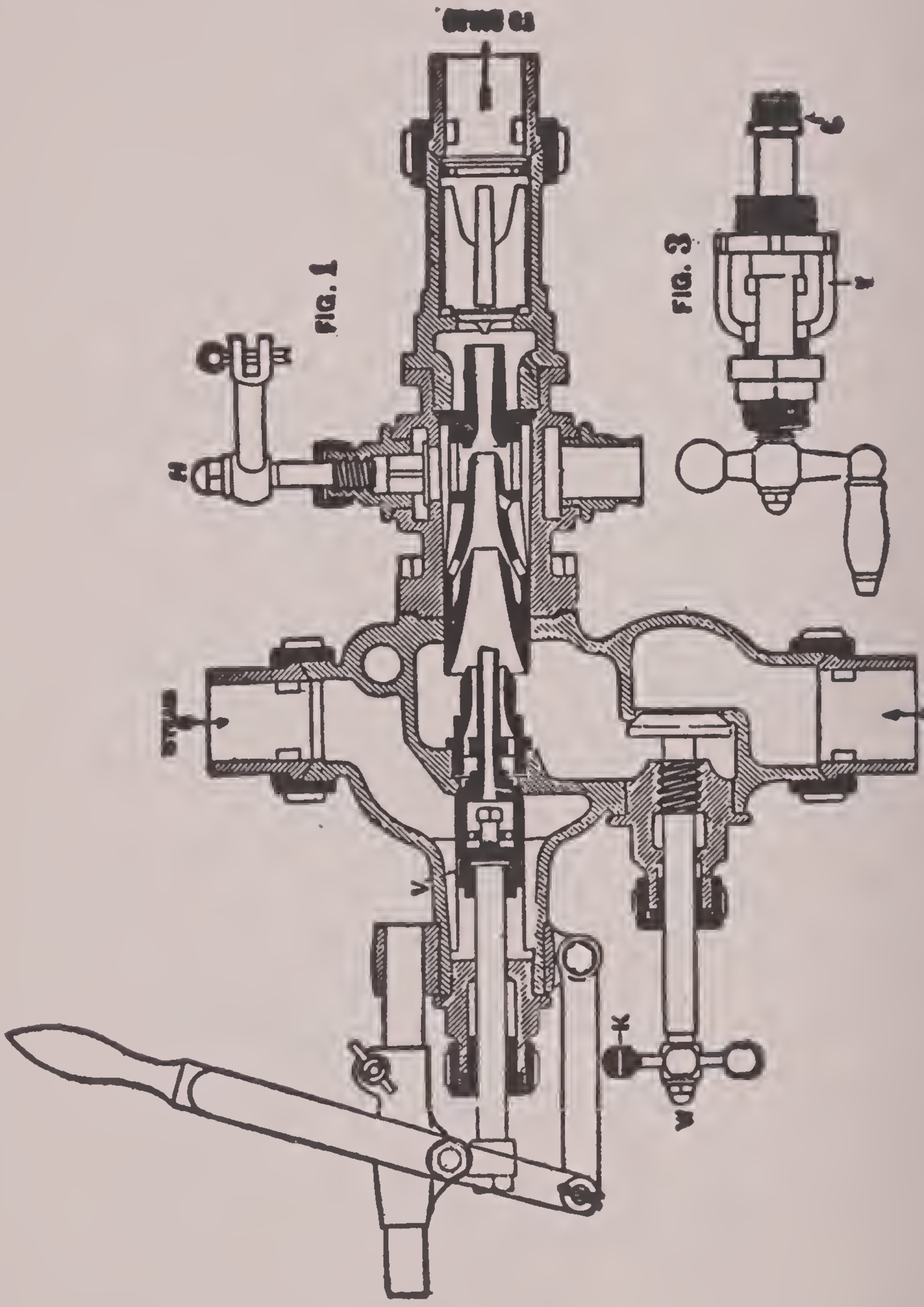


Fig. 130. No. 88 "Monitor"—Interior View.

Description of '88 Monitor, Fig. 130. This injector is a modification of the well-known locomotive injector of that name, and is designed to supply the demand for a lever-handled injector, and embody in a new combination all the best qualities of the former instrument. The most prominent feature of the '88 Monitor is the facility with which it can be started and stopped by the new lever-handle attachment, or the single screw spindle motion, whichever may be preferred. The quantity of water which the new injector is capable of throwing, will command attention, and the range of its capacity, running as it does from 100 per cent at maximum to less than 50 per cent at minimum, makes it equally applicable to the moving of heavy or light trains, as the case may happen.

It will lift the feed-water 5 ft. at 30 lbs. pressure, and at standard working pressure, to a height not likely to arise in ordinary locomotive practice.

Its pipe connections are the same as the other Monitors and interchangeable therewith, so that in the use of the new instrument, the old fittings, if they are good, need not be disturbed.

The construction of the starting arrangements is such that the screw attachment can be readily substituted for the lever-handle, should the former method be preferred.

Directions for Application. Place the injector above water level in tender. Take steam from dome, or highest part of boiler, through dry pipe. This will insure the best effects.

Instructions to Operate the Injector. *With Lever Motion.* To start: Pull out the lever a short distance to lift the water; when water runs from the overflow, steadily draw back the lever until overflow ceases. Do not increase the steam supply after overflow has ceased.

Regulate for quantity with water-valve W.

To stop: Push in the lever.

With Screw Motion. To start: Open the steam valve one-quarter of a turn to lift the water. When water runs from the overflow, open steam valve until overflow ceases. Do not increase the steam supply after overflow has ceased.

Regulate for quantity with water-valve W.

To stop: Close steam valve.

Note 1. To grade injector: Throttle water by valve W; if this is not sufficient, reduce the steam by pushing in lever handle about half-way, and in case of the screw motion, by screwing in the steam spindle about half-way.

2. To use as a heater: Close valve H and pull out lever all the way, and in case of screw motion open valve full. At all other times valve H must be kept open.

3. The heater cock can be worked from the cab by means of arm A, adapted for the attachment of an extension rod. Arm A is held on the heater cock spindle by friction, and by loosening cap C it can be set at any angle to suit the most convenient position for the extension rod.

4. The hole in the top knob K of water handle W indicates the position of the water valve. One turn of the handle fully opens. or entirely closes, the water passage. In either case, the knob with the hole in should be in an upright position. Intermediate positions of the knob K indicate corresponding openings in the water passage.

The Little Giant Locomotive Injectors, Fig. 131, made by the Rue Manufacturing Co., Philadelphia, have been on the market for many years. This injector is simple in construction, and is not liable to get out of order.

These injectors are fitted with a movable combining tube, operated by a lever which allows them to be adjusted to work correctly at different pressures of steam, and under the many conditions which injectors are required to work.

TABLE 19—SIZE AND CAPACITY

Size of Injector	Copper Pipe Outside		Iron Pipe Inside		Gallons of Water per hour
	Steam	Water & Delivery	Steam	Water & Delivery	
4	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	600
5	$1\frac{1}{8}$	$1\frac{1}{8}$	1	1	950
6	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	1275
7	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	1800
8	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	2250
9	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	2800
10	$1\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{2}$	2	3500

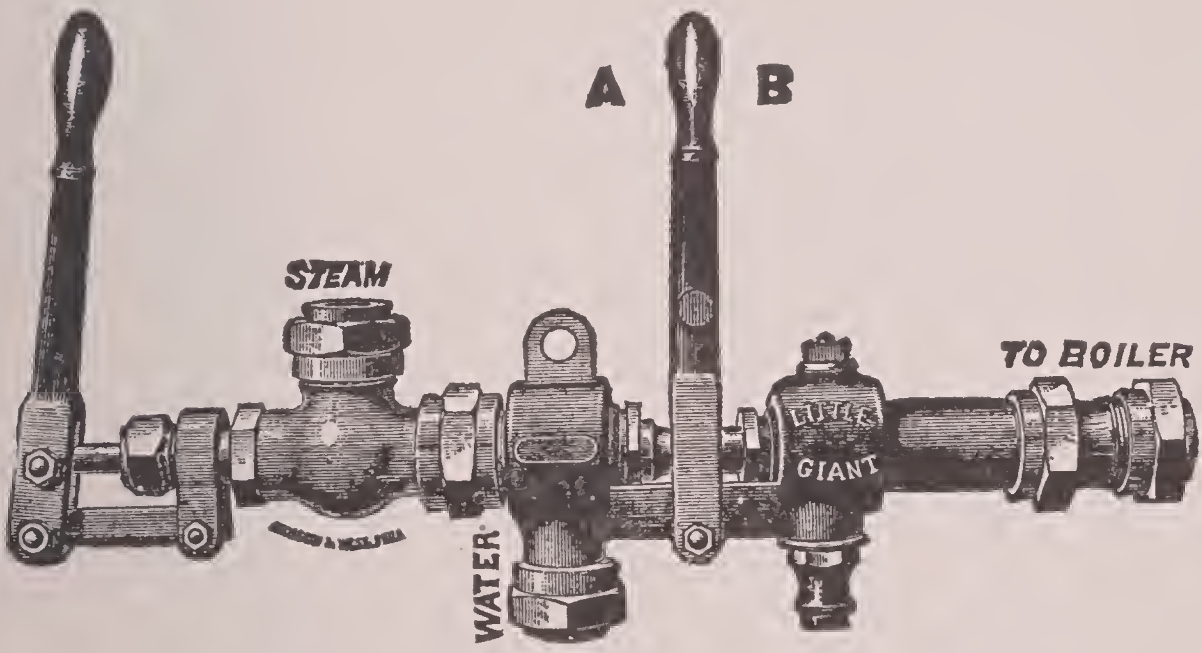


Fig. 131.

To Operate. Have the combining tube in position to allow a sufficient quantity of water to condense the steam when the starting valve is full open, then open the starting valve slightly; when water shows at overflow, open full. Regulate the water by moving the combining tube. To use as a heater, close overflow by moving the combining tube up against the discharge, then open starting valve enough to admit the quantity of steam required.

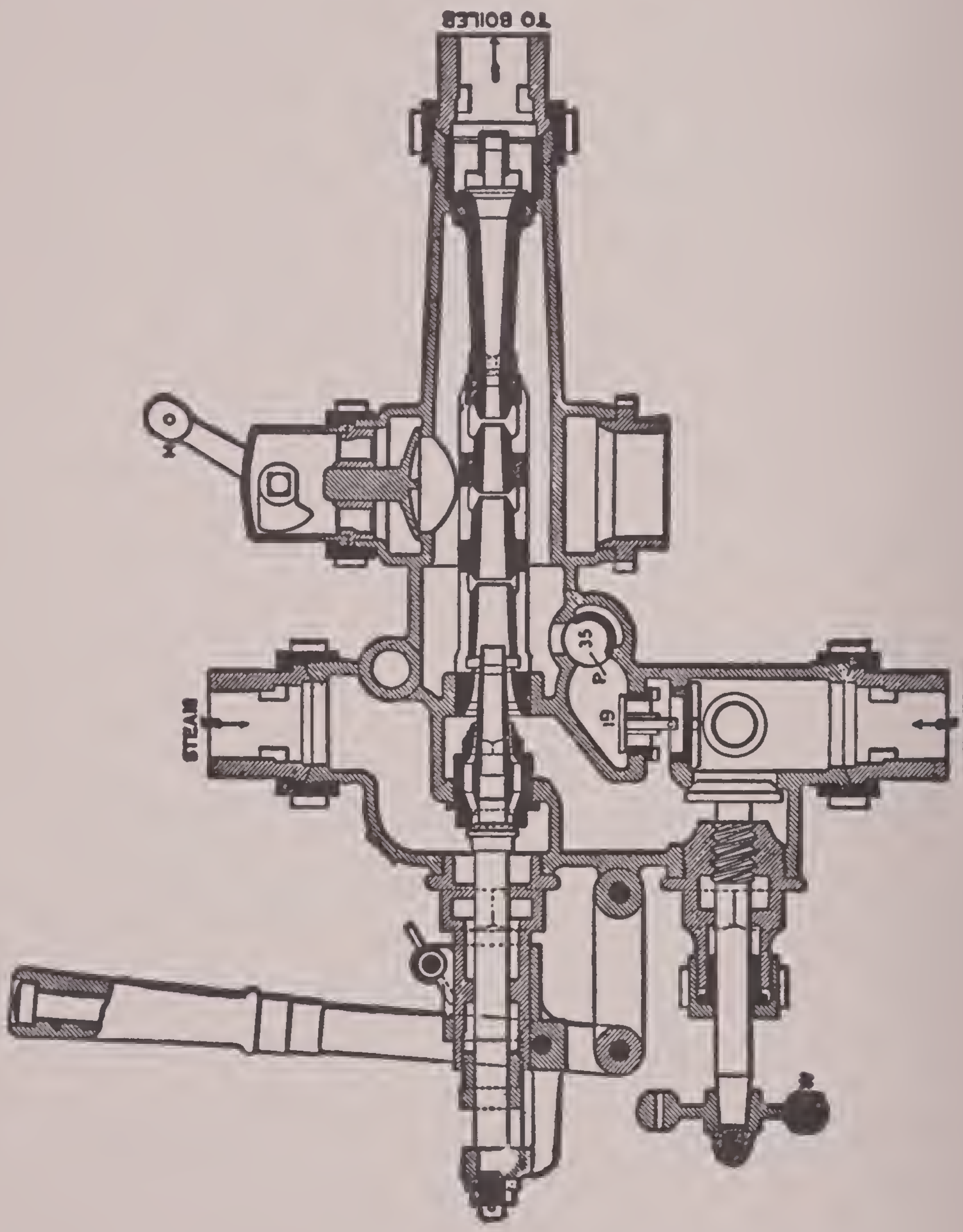


Fig. 132. The Simplex Injector.

The Simplex Locomotive Injector, Fig. 132, has been designed to meet the severe requirements of modern locomotive practice, especially where it is desired that the instrument be self-adjusting and re-starting.

Attention is called to the largely increased delivering capacities at the high steam pressure of locomotive engines of to-day.

This injector is of the "re-starting" type, and if the water supply should happen to be temporarily interrupted, the instrument will start again without any manipulation, just as soon as the water supply is again within reach. The instrument is also "self-regulating" and requires no water valve regulation above 50 lbs. steam pressure, to prevent spilling at the overflow. Its lifting qualities are of the highest order, and it may be relied upon to start promptly after doing duty as a heater.

The throttling capacity is fully 50 per cent of the maximum capacity under ordinary variations of lift and of feed water temperature.

If it is desired that the instrument be placed outside the engine cab, and operated by means of extension rods, a quick motion screw attachment can be readily substituted in the place of the lever handle.

The construction of the injector is such that all its interior nozzles and other component parts are easily accessible for examination and repairs.

Method of Operating. To start: Pull out the lever.

To stop: Push in the lever.

Regulate for quantity by means of the water valve.

To use as heater for the feed water: Close heater cock and draw out the lever.

In starting on high lifts and in lifting hot water, pull the lever out slowly.

In case a pipe is attached to the overflow, its inside diameter must under no circumstances be less than the inside diameter of the overflow nozzle.

If the water inlet valve (part 19 of details) should leak and prevent the prompt lifting of the feed water, it will only be necessary to turn around key 35, so that the letter "S" (not shown on cut) on the square spindle-end will be "up." This will close passage "P," and permit the continued use of the instrument until valve 19 can be repaired.

The Simplex injector is made by the Nathan Mfg. Co. of New York, who furnish the following table of capacities.

TABLE 20.

Size	Capacity in Gallons p'r Hour		Inside Diameter of Iron Pipes, in Inches			Outside Diameter of Copper Pipe, in Inches		
	125 lbs.	200 lbs.	Steam	Suction	Delivery	Steam	Suction	Delivery
5	990	1140	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$
6	1260	1440	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$
7	1830	1950	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$
8	2280	2580	$1\frac{1}{2}$	2	2	$1\frac{3}{4}$	2	2
9	2880	3240	$1\frac{1}{2}$	2	2	$1\frac{3}{4}$	$2\frac{1}{4}$	2
10	3450	3800	2	2	2	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$

LUNKENHEIMER '99 MODEL STANDARD INJECTOR. Figs. 133-134. This injector embodies in its construction all desirable features which tend to make an injector high grade and efficient. Under high steam pressures it is necessary to have a machine which can be operated as efficiently as under low pressures, and one which admits of sufficient range of work to cover all conditions of service.

The construction is simple, manipulation easy, and the results attained show a high degree of efficiency. It can be started promptly, under most conditions, at all pressures from 30 to 250 lbs., and can be handled without fear of uncertainty of action, as it is not sensitive in this respect. It will work without adjustment of steam or water from 40 to 250 lbs. and higher, and the capacity can be reduced over 50 per cent at all points. This feature makes it especially suitable for severe service, such as is found on railroads, steamboats and high-pressure power plants, and in other places where the load varies and it is necessary to have an injector in which the capacity can be reduced within wide limits.

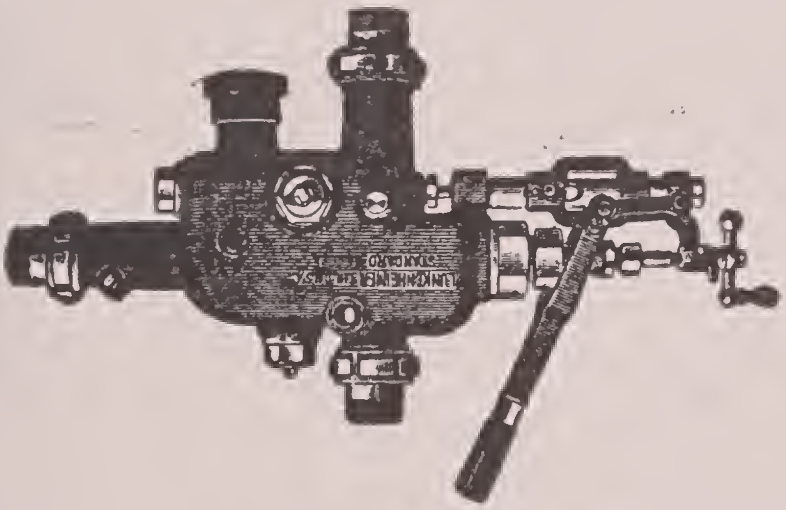


Fig. 133. Lunkenheimer '99 Model Standard Injector.

The design of the machine is excellent, the parts are well proportioned, the operating mechanism which controls the steam and overflow valves is not complicated and is all contained within the body of the injector, and there are no outside connecting rods, usually found in machines of this class.

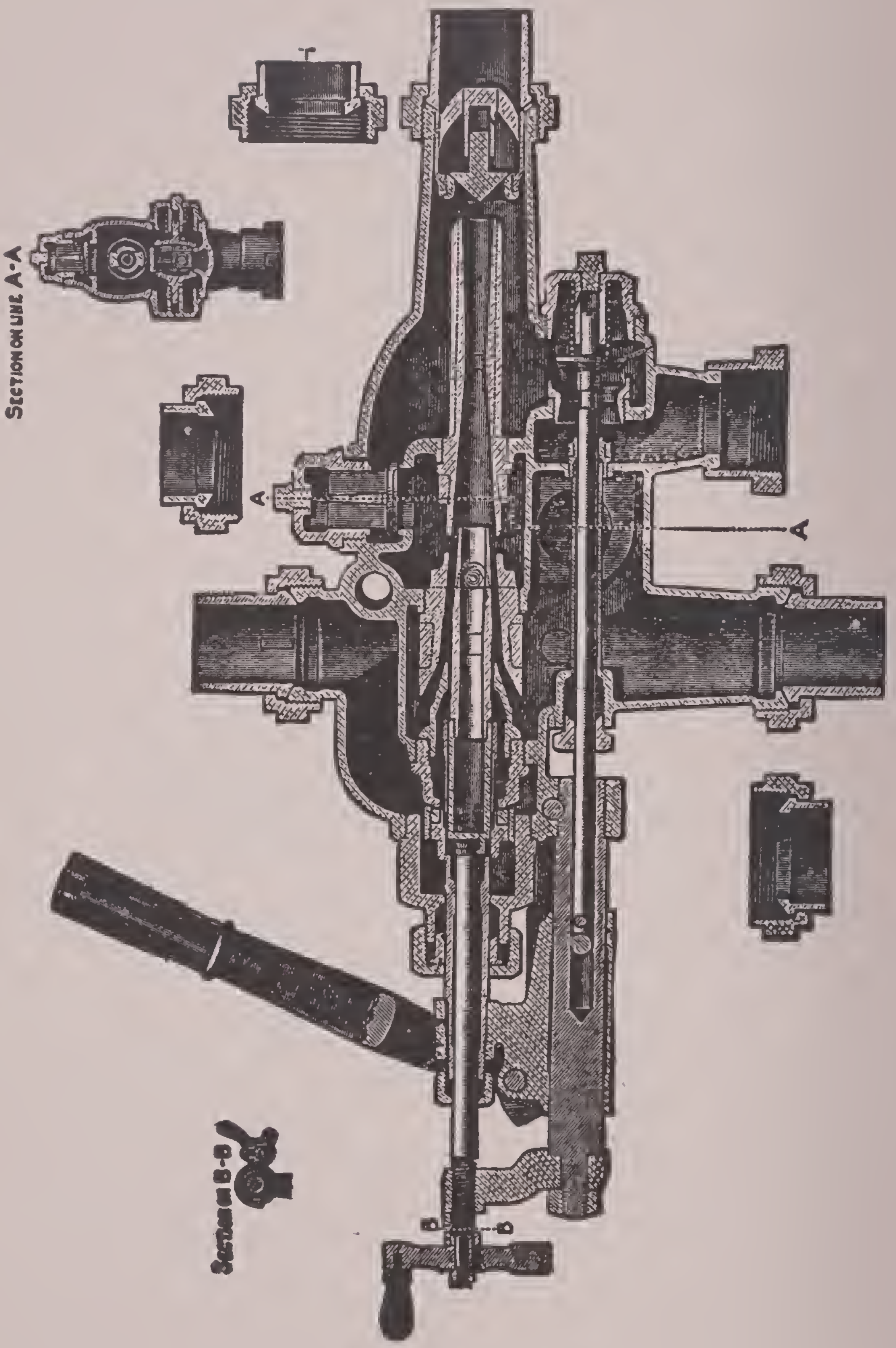


Fig. 134. Lunkenheimer '99 Model Standard Injector—Sectional View.

TABLE 21.

CAPACITIES OF THE LUNKENHEIMER STANDARD INJECTOR.

Size No.	Pipe Con. Steam, Suction Delivery	Pipe Connections Overflow	Maximum Capacities at Various Steam Pressures Feed Water, 76° F. Lift, 5 feet.				
			125lbs.	150lbs.	175lbs.	200lbs.	225lbs.
8½	¾″	½″	650	665	682	700	715
9½	1″	¾″	835	855	876	900	925
10½	1¼″	1″	1110	1140	1170	1200	1230
11½	1¼″	1″	1485	1520	1560	1600	1640
12½	1½″	1¼″	1865	1910	1950	2000	2050
13½	2″	1½″	2320	2375	2440	2500	2560
14½	2″	1½″	2780	2850	2925	3000	3080
15	2″	1½″	3430	3518	3610	3700	3795
15½	2″	1½″	3820	3910	4000	4100	4200
16½	2½″	2″	4640	4760	4875	5000	5130

THE HANCOCK LOCOMOTIVE INSPIRATOR. The Hancock inspirator consists of one apparatus for lifting and one for forcing. The original stationary type embodied this feature by incorporating two chambers side by side, connected at the top for steam, and at the bottom for water, so that it was apparent to the casual observer that each carried its own set of apparatus. The Hancock inspirator works successfully under the most severe conditions. With high or low steam pressure, on all lifts up to 25 feet, when taking feed water under a head, with hot feed water as well as cold, for all steam pressures and for all conditions, its operation is the same and it requires no adjustment for varying steam pressures.

The lifting apparatus consisted of a steam nozzle and a combining tube. The throat of the combining tube being so much larger than the smallest opening in the steam nozzle enables it to increase or diminish the amount of water as the pressure of steam increases or decreases. As pressure of steam increases, the pressure in the forcing chamber or delivery chamber of the lifter is increased, enabling the water to enter the forcer combining tube against the increased tension of the steam from the forcing nozzle, thus enabling it to work from low pressures to high without any adjustment of either steam or water supply. The forcing or combining tube being made without any openings between its mouth and discharge end, permits of the steam and water combining up to a very high temperature, the overflow being closed positively.

The above described apparatus as made and used was provided with a separate valve for opening and closing the intermediate overflow in starting, and valve for opening and closing the steam to the forcer and the final overflow valve. While each was very simple in construction and the operating of the inspirator was easily understood, still for locomotive purposes it was considered that the functions performed by the valves above mentioned should be brought under the control of one operating lever.

To accomplish this, the Hancock locomotive inspirator, Fig. 135, operated by a single lever, was evolved, and is made in different types to suit different connections.

The present Hancock locomotive inspirator will work successfully with pressures of steam from 35 lbs. to 350 lbs. without any adjustment of either steam or water, and the proportions are such as to increase its quantity of water from 35 lbs. to 200 lbs., this being about the average pressures carried on locomotives, and while its maximum capacity is at 200 lbs. the percentage of decrease from 200 lbs. down to 160 lbs. is not enough to interfere with the requirements of the locomotive. It will lift water promptly on the highest lifts encountered in locomotive practice, even if the suction becomes heated or filled with hot water.

It will take feed water at a temperature of 125° reliably with a steam pressure of 200 lbs. Tests have been made where the inspirator has taken water on a lift of two feet at 132° with 200 lbs. of steam and at 140° with 140 lbs. of steam.

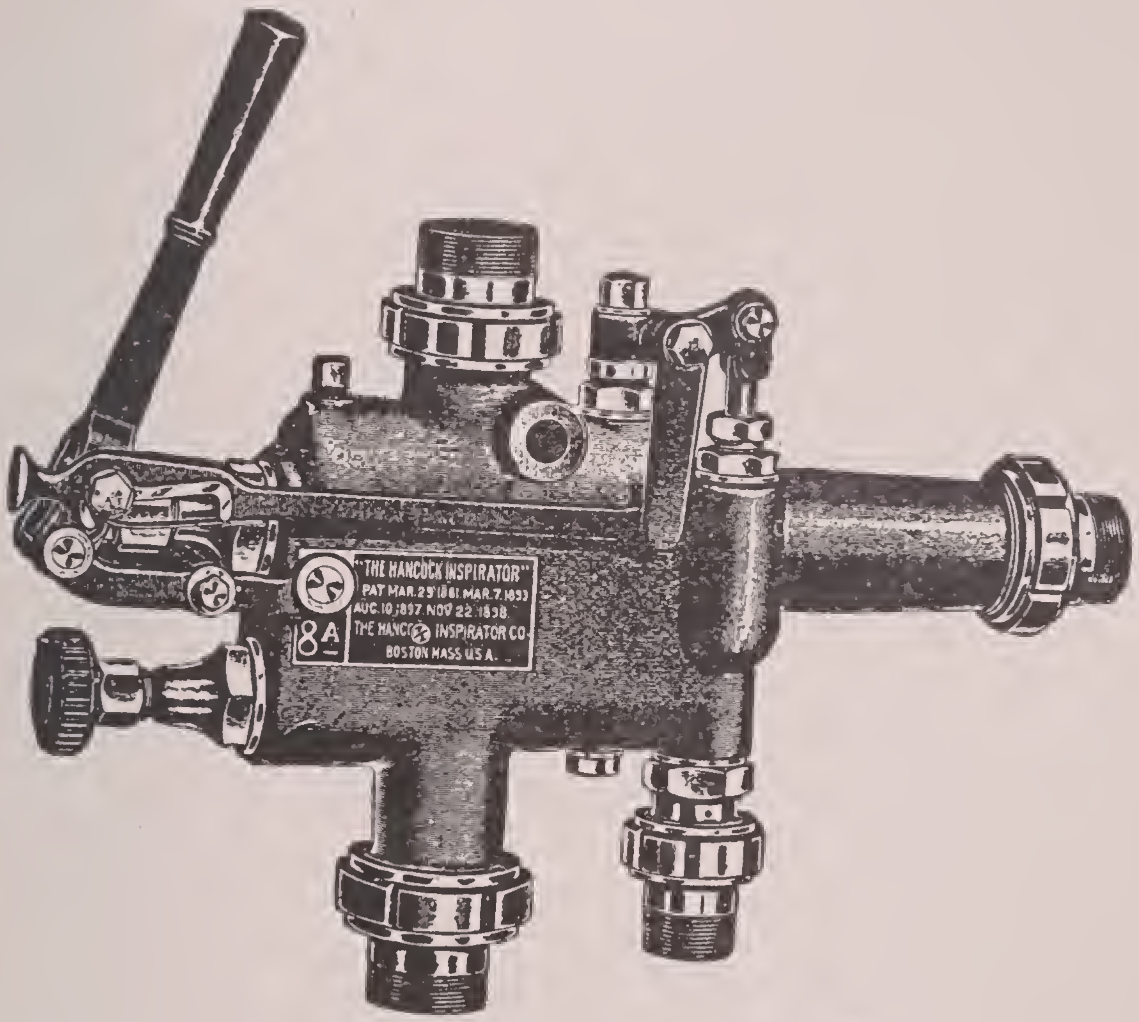

"THE HANCOCK INSPIRATOR"
PAT MAR.29'1881. MAR.7.1893
AUG.10,1897. NOV 22.1898.
THE HANCOCK INSPIRATOR CO.
BOSTON MASS U.S.A.
8A

Fig. 135. The Hancock Inspirator.

Regulation from Maximum to Minimum. The regulation of this machine from maximum to minimum is accomplished by simply reducing the amount of steam supplied to the lifting apparatus.

As has been before mentioned, the combining tube has no openings between its mouth and delivery end, and it admits of a positively closed overflow; hence all water passing through the combining tube must go to the boiler and cannot escape at the overflow. This condition is possible on account of the two sets of tubes, the lifting tube acting as a regulator and governor for the forcer, hence requiring no adjustment from the lowest to the highest steam pressures within its entire range.

Internal Arrangement. The intermediate overflow valve operates automatically, its only function being to give direct relief to the lifter steam nozzle when lifting or priming, and comes to its seat when the forcer steam is applied and is held there by the pressure exerted by the forcer.

An observation of the internal parts of this instrument, Fig. 136, will show at once the simplicity of its construction and the ease with which it can be repaired and parts renewed.

Material. In the manufacture of the Hancock locomotive inspirator the formulae used in the composition of the material for the several parts have been selected especially for the service each part has to perform. The tubes and valves are made of composition that does not contain zinc. Other parts are constructed of material that will produce the least wear with its companion piece. As with the high temperatures incident upon high pressure of steam, care has been taken in the selection of the composition of parts that would work in harmony without abrasion. The bodies are made of a composition containing about 10 per cent of tin.

The Hancock Inspirator Co. furnish the following table of capacities and sizes of pipe connections for type A:

TABLE 22.

CAPACITIES AND SIZES OF PIPE CONNECTIONS.

Size	Capacity per Hour		Pipe Connections							
	Steam Pressures		Steam		Suction		Delivery		Overflow	
	160 Pounds	210 Pounds	Iron	Copper	Iron	Copper	Iron	Copper	Iron	Copper
5	1180 gals.	1210 gals.	1½	1¾	1½	1¾	1½	1¾	1¼	1½
6	1605 gals.	1647 gals.	1½	1¾	1½	1¾	1½	1¾	1¼	1½
7	2095 gals .	2151 gals.	1½	1¾	1½	1¾	1½	1	1¼	1½
8	2651 gals.	2723 gals.	2	2	2	2¼	2	2	1½	1¾
9	2954 gals.	3034 gals.	2	2	2	2¼	2	2	1½	1¾
10	3961 gals.	4068 gals.	2	2¼	2½	2¾	2	2¼	2	2¼
11	4700 gals.	4810 gals.	2½	2¾	3	3¼	2½	2¾	2	2¼
12	5700 gals.	5950 gals.	2½	2¾	3	3¼	2½	2¾	2	2¼

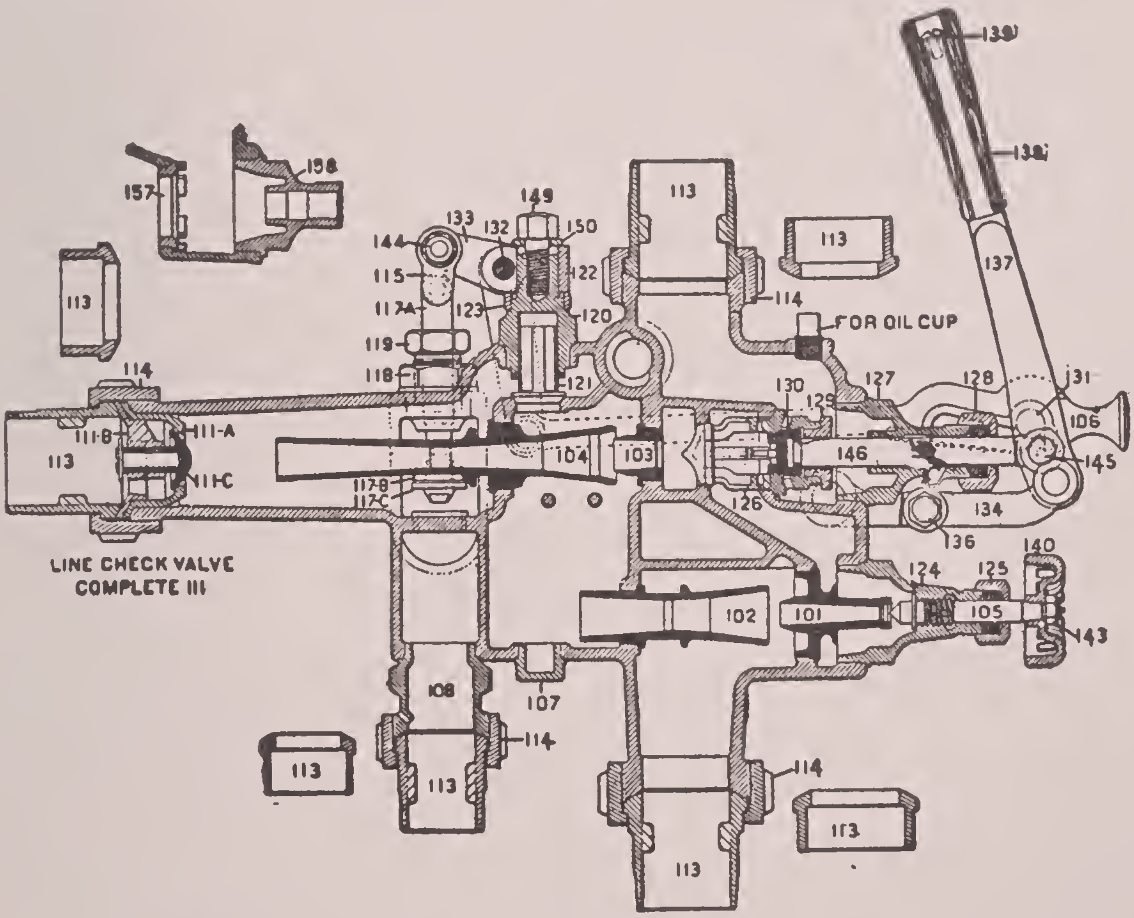


Fig. 136. The Hancock Inspirator—Sectional View.

Type A Hancock inspirator will interchange and fit the Monitor coupling connections.

Hancock inspirators, type A, sizes 5 and 6, have the same size body and interchange. Sizes 8, 9 and 9½ have the same size body and interchange.

Type B Hancock inspirator will interchange and fit the Sellers coupling connections.

Hancock inspirators, type B, sizes 5, 6 and 7, have the same size body and interchange. Sizes 8, 9 and 9½ have the same size body and interchange.

The Hancock inspirators, types A, B and D, differ only in the form of the bodies and connections. All internal parts are the same for corresponding sizes. All external parts are the same for corresponding sizes, except part No. 106 (connecting rod).

DIRECTIONS FOR CONNECTING AND OPERATING. To obtain the best results, locate the inspirator with the overflow nozzle about 4 in. above the water in the tank. Take the steam through a dry pipe from the dome. Connections from the inspirator to the dome must not be smaller than the inside diameter of the size of copper pipe given in Table 22. The openings in the suction or feed pipe connections from the inspirator to the tank must not be smaller than the inside diameter of the sizes of iron pipe given in Table 22.

Overflow Pipe. An ordinary source of annoyance very often occurs from the overflow nozzle, or overflow pipe becoming filled up, contracting the openings so that the inspirator will not lift or prime promptly. Sometimes it occurs that when the overflow nozzle is all free and clear, the overflow pipe is apt to escape the attention of the person doing the repairs or overhauling the inspirator, and is reported not working satisfactorily.

It is almost impossible to ascertain this without removing the pipe. These pipes should always be looked over and kept free.

Intermediate or Line Check Valve. The intermediate or line check valve in the delivery pipe should receive attention. The line check valve in the delivery end of the inspirator, in case of impure water, should be looked after frequently. When the inspirator is provided with a swing check valve, care should be taken to keep this valve clear from deposits resulting from impurities in the water.

Suction Pipes. Where iron suction pipes are used, especially if the pipe is in two pieces and connected by unions, they should be carefully watched to see that they are absolutely tight and well supported, as a very slight leakage of air will materially reduce the capacity of the inspirator, and if too large a quantity of air is admitted it will cause the inspirator to break.

In General. It is very important that there should be ample steam and water supply to all types of the Hancock inspirator. It sometimes occurs that the inspirator will not work satisfactorily with the regulating valve wide open or at its maximum, but will work when this valve is partially closed or when at its minimum. This indicates clearly an insufficient steam supply. It may be due to the contracted openings in the valve next to the boiler, combination box, or too small dry pipe leading to the combination box, and should be remedied. An insufficient supply of water caused by too small size or restricted opening in the tank valve, too small opening in the goose neck leading to the tank, too small area in the strainer, a kinked or partially collapsed hose, or leaks in the suction pipe, would cause the inspirator to break.

Operation. To start the inspirator, draw the lever, part No. 137, Fig. 136, back to lift the water, then draw it back to the stop. When the lever, part No. 137, is drawn back slightly, steam is admitted to the lifter steam valve, part No. 130, through the forcer steam valve, part No. 126, to the lifter steam nozzle, part No. 101. The flow of the steam into the lifter tube, part No. 102, creates a vacuum, and causes the water to flow through the lifter tube, part No. 102, condensing the steam, and out through the intermediate overflow valve, part No. 121, and through the final overflow valve, part No. 117, in the delivery chamber. A further movement of the lever, part No. 137, opens the forcer steam valve, part No. 126, admitting steam to the forcer steam nozzle, part No. 103, and to the forcer combining tube, part No. 104, creating a pressure in the delivery chamber sufficient to close the intermediate overflow valve, part No. 121, and open the intermediate or line check valve, part No. 111. The final overflow valve, part No. 117, will be closed and the inspirator in full operation when the lever is drawn back to the stop. When the pin in the wheel of the regulating valve is at the top, the inspirator will deliver its maximum quantity of water; to reduce the feed, turn the regulating wheel to the right.

Regulating. To use the patent heater attachment, lift the connecting rod, part No. 106, until disengaged from the stud in the lever, part No. 131, then draw back the connecting rod to close the overflow valve, part No. 117. Draw the lever back to the point used in lifting. This will usually give all the steam that is required for a heater. If the amount going back is too large, regulate it by the regulating wheel to give just the amount required, as with the lever in the position described all the steam blowing back would pass through the lifter nozzle. Thereby the closing of the main steam valve at the boiler becomes unnecessary.

Type Composite. The Hancock composite inspirator, Fig. 137, consists of two separate and individual inspirators within one body or casing, which can be operated separately or simultaneously, as desired. Where it may be desired to locate both injectors on one side of the locomotive, convenient to either the engineer or fireman who has charge of pumping the engine, or on the boiler butt, available to both, the advantages of the composite are apparent. Owing to the limited room in the cab, it is generally difficult to locate both instruments so that they can both be operated by the engineer and be equally convenient.

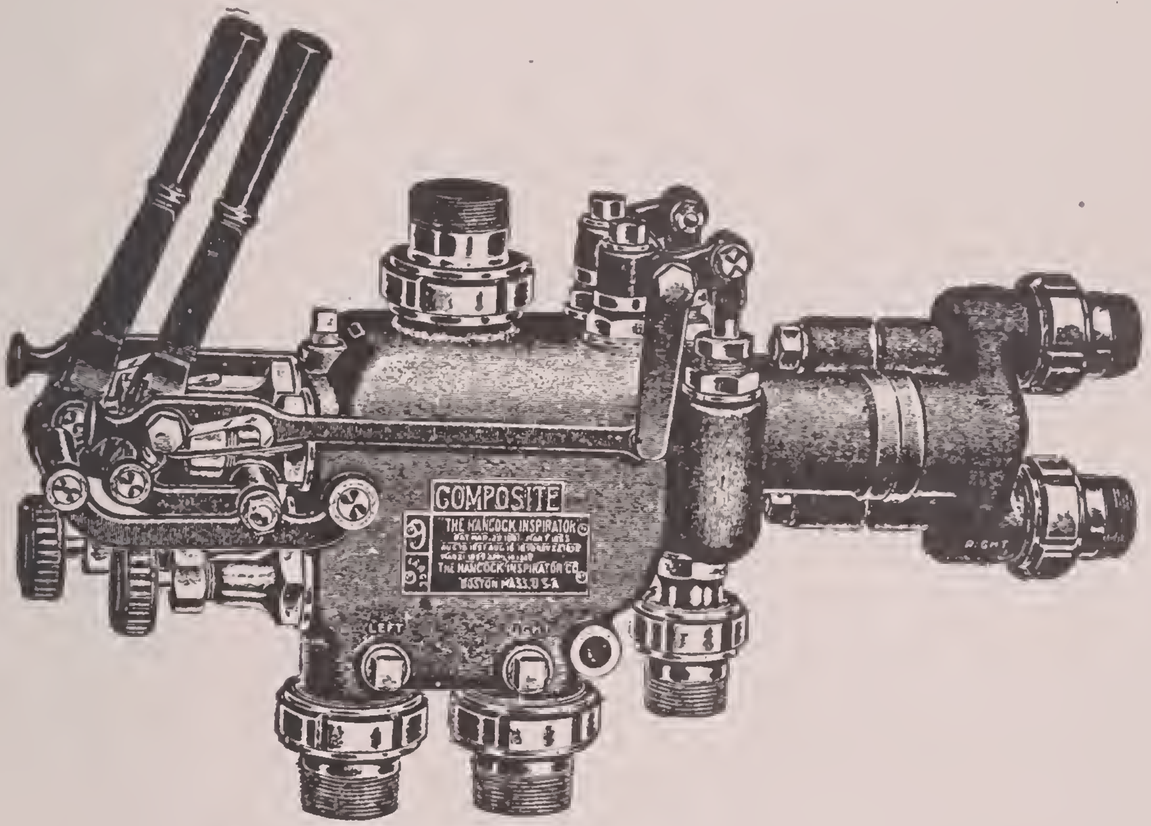


Fig. 137. Hancock Inspirator, Type Composite.

It occupies but little more space than a single inspirator or injector, and owing to its compactness it has been found that it can be located in positions where in the past it has not been possible to locate two separate instruments.

It places both instruments directly under control of the engineer, and both are equally convenient to operate, the result being that both instruments are operated and kept in good order.

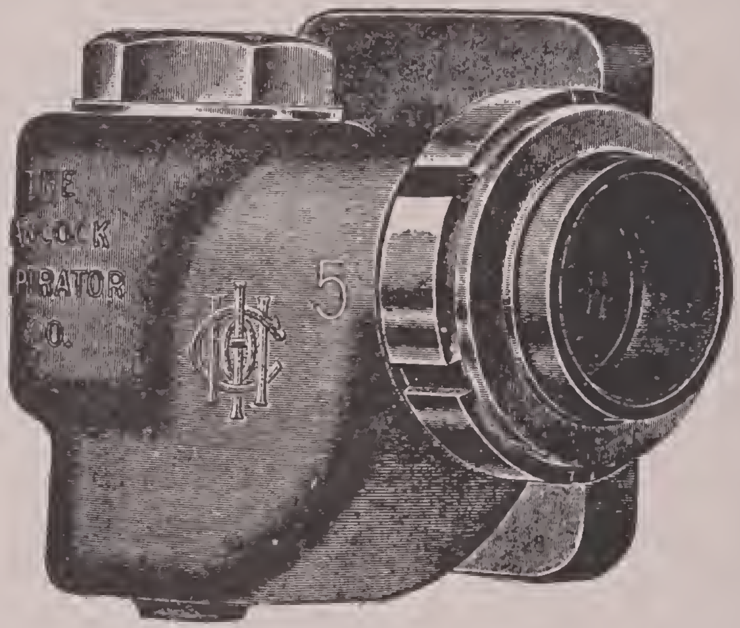


Fig. 138. The Hancock Main Boiler Check Valve.

Each instrument has an independent suction pipe, delivery pipe and line check valve, thus enabling each to be operated independent of the other.

In attaching the composite inspirator (either to back head or side of boiler), one steam valve, one steam pipe, one overflow pipe and one opening into the boiler are dispensed with, thus effecting a very considerable saving of material and labor which would be required with two separate instruments.

The operation of the Hancock composite inspirator is the same as the Hancock inspirator, types A, B and D. To operate either instrument, draw the lever back until the water is lifted, then draw it back as far as it will go. To put both instruments in operation, start one and then the other.

It is desirable to use a double check valve in connection with the composite inspirator.

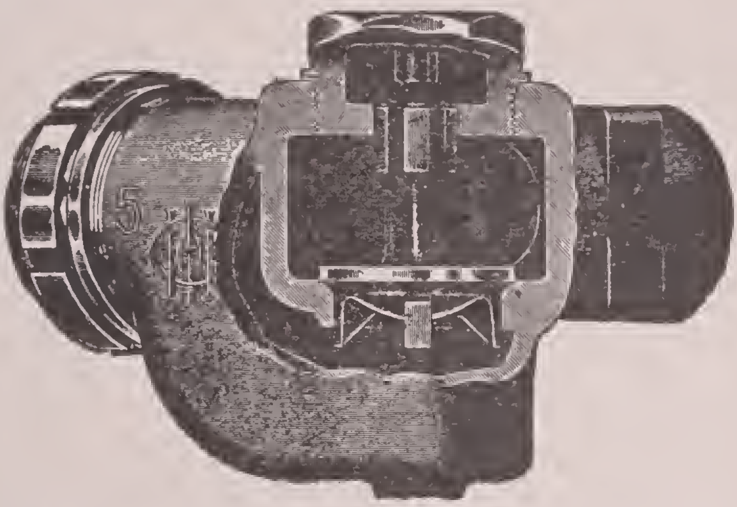


Fig. 139. Sectional View of the Hancock Main Boiler Check Valve.

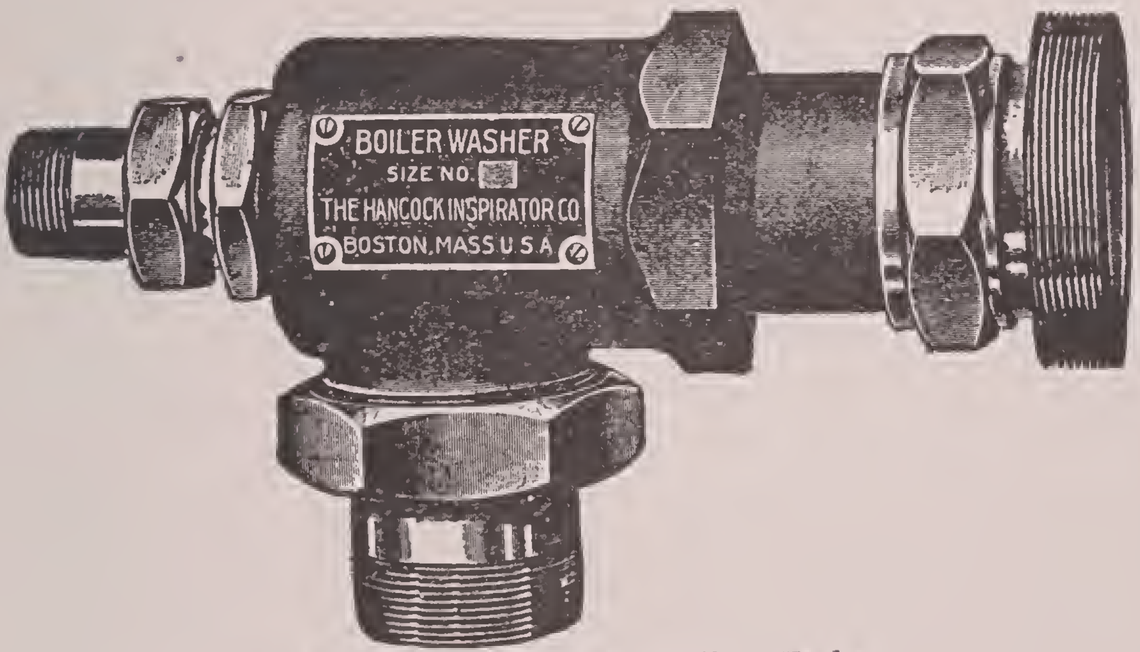

BOILER WASHER
SIZE NO.
THE HANCOCK INSPIRATOR CO.
BOSTON, MASS U.S.A

Fig. 140. The Hancock Boiler Washer.

The Hancock Boiler Washer. Fig. 140. A perfectly simple and durable apparatus for washing boilers. Will either lift water from 15 to 20 feet or take it under a head.

At a steam pressure of 100 lbs. the temperature of the delivery water will be about 120° Fahrenheit, or as hot as it can be conveniently handled.

The hose or delivery end of the boiler washer is left blank, to be threaded to fit hose couplings in use, or will be threaded as desired.

TABLE 23.

CAPACITIES AND SIZES OF PIPE CONNECTIONS.

Size	Capacity per Hour, Steam Pressure 60 Pounds	Pipe Connections		Discharge Nozzle for end of Delivery Hose
		Steam	Suc. and Delivery	
Small.	2200 gals.	¾ inch.	1½ inch.	¾ inch.
Medium...	3900 "	1 "	2 "	1 "
Large.....	6000 "	1¼ "	2½ "	1¼ "

Pipe Connections. For steam, suction and delivery connections, see above table.

Place a globe valve in the steam pipe for a starting valve, and another valve in suction pipe for a water valve.

If the boiler washer is to lift water, there should be an overflow or outlet pipe not smaller than one inch in size connected to the delivery pipe. Place a valve in this overflow pipe.

Operation. If the boiler washer takes the water under a head, open the water valve in the suction pipe and then open the valve in the steam pipe.

Vary the temperature of the delivery water by regulating the steam and water supplies with either the starting or water valve or both.

If the boiler washer lifts the water, open both the valve in the overflow pipe and the water valve in the suction pipe, and give steam with the starting valve.

When water appears at the overflow, close the valve in the overflow pipe, and vary the temperature of the delivery water by regulating the steam and water supplies with either the starting, or water valve or both.

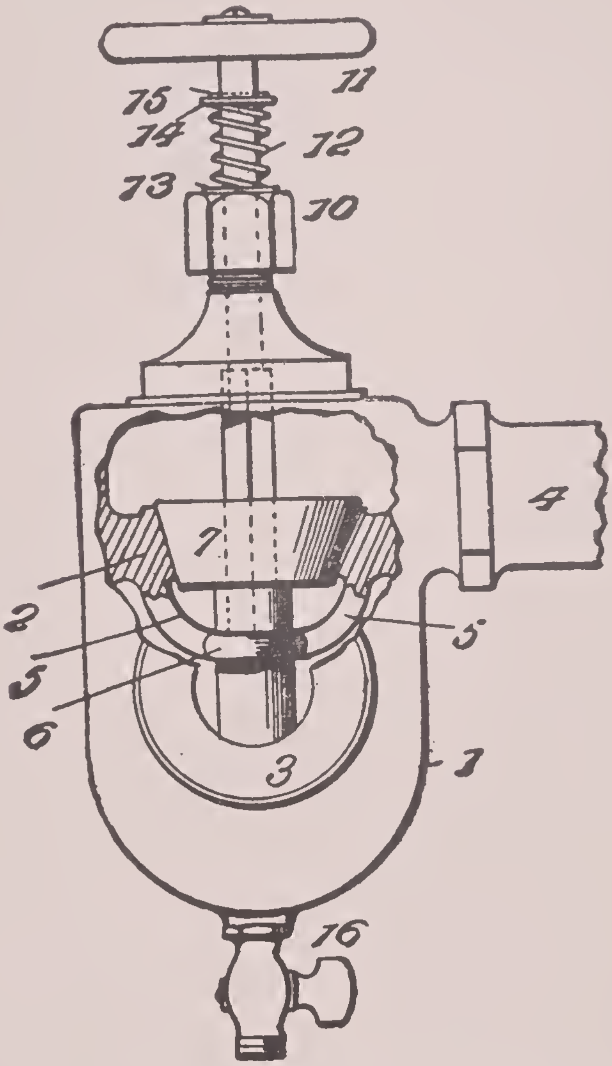


Fig. 141. Thom Check Valve—Side Elevation.

THE THOM CHECK VALVE.

An improved check valve for locomotives has been invented and patented by Mr. John C. Thom. The following claims are made for this valve by the inventor. First, that a secure seating of the valve will always be insured.

Second, that the valve can be readily ground upon its seat in order to remove any scales, or dirt that may have formed thereon.

Third, that the valve is effective in operation, simple and durable in construction, and easily and cheaply manufactured.

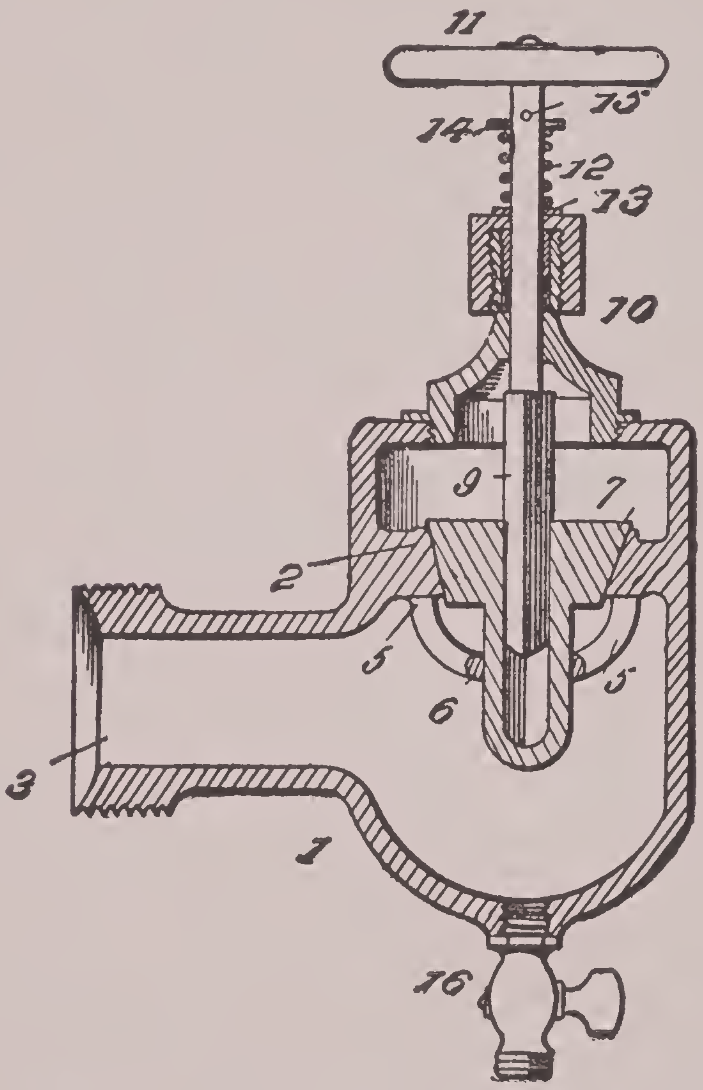


Fig. 142. Thom Check Valve—Sectional View.

As will be seen by reference to Figs. 141 and 142, it consists essentially of a valve provided with a tubular stem, having a telescoping and interlocking connection with the spindle.

The following specifications and description, together with the illustrations are reproduced from the Locomotive Firemen's Magazine.

Fig. 141 is a side elevation of the valve with parts broken away. Fig. 142 is a sectional view on the line *x-x* of Fig. 141.

The numeral *1* designates the casing which is subdivided into two compartments by a diaphragm, *2*, having an opening therein which forms the valve seat, the lower compartment having communication with the water inlet, *3*, while the upper compartment has communication with the outlet, *4*, leading to the boiler. Pendent from the valve seat are arms, *5*, which support a ring, *6*, and form a guide for the valve stem. The valve itself comprises a disk, *7*, having beveled edges so as to fit snugly against the valve seat and provided with a tubular stem with an angular opening therein and extending downward through the ring, *6*. The lower portion of the spindle, *9*, is made angular so as to fit into the opening in the valve stem while the upper portion passes through the packing box, *10*, so as to have a rotary and longitudinal movement, and is provided for at its extremity with the usual handle, *11*. This spindle is normally held in a raised position by means of a spring, *12*, which surrounds the upper portion thereof and is interposed between a washer, *13*, on the top of the packing box and a similar washer, *14*, held in position by a key, *15*, passing through the spindle. A drain cock, *16*, may be attached to the lower chamber to enable any sediment to be withdrawn.

Owing to the fact that the spindle, *9*, is normally in a raised position, the feed water can readily pass through the valve into the boiler, but any back flow thereof is prevented. When the valve is raised from its seat it telescopes upon the spindle, *9*, and hence is prevented from tilting, and will accurately fall back into position. The guide members formed by the pendent arms, *5*, also cooperate to insure a correct seating of the valve. Should any scale or dirt get between the valve and valve seat they can be readily removed under the pressure from the boiler by turning the handle, *11*, back and forth, which results in grinding the valve upon the valve seat. If desirable, pressure may be exercised in grinding the valve by pushing downwardly upon the handle, *11*, at the same time it is turned.

BOILER CHECKS STICKING.

On the subject of the sticking up of boiler check valves Mr. D. R. McBain presents the following timely suggestions in the Locomotive Firemen's Magazine: "This matter is of somewhat serious consequence, especially on fast trains, where getting out on the running board and striking the check with a hammer is about the only thing that can be done. The trouble usually occurs at times when the steam pressure is high, but it is not confined to that condition. The writer has noted several cases wherein checks have stuck open when the steam was not more than one-half of the boiler pressure, and, when checks were taken down for examination, they were found in apparently equally good shape.

"While it is an undisputed fact that more checks stick up at high pressure than at low, I believe the difference is due to the fact that there are more opportunities afforded (shutting off injector) while engines are under full pressure than there are when pressure is not high, and

I am therefore forced to assume that the amount of pressure on the boiler at the time has little, if anything, to do with the trouble. Some boiler checks are so constructed that after several months of use the check when open makes a steam-tight joint on top of the cage, thus lessening the area for pressure on top to close the valve when the injector is shut off. In this connection it must be remembered that when an injector is being started the pressure in the branch pipe is higher than that in the boiler and after the check raises the pressures are about equal. Assuming then that the valve has made a steam joint in the top of the cage, it will be evident that so long as the pressure in the branch pipe is up to boiler pressure, or even quite a little below that, and this pressure is exerted on the under surface of the valve, which, on account of the joint on the top of the cage, is much greater than the surface exposed at the top, the check will stay open. When a check valve sticks open the area of its bottom is exposed to boiler pressure and if the boiler pressure does not go down (and that seldom does occur), the check, if making a joint on the top of the cage, will not go down. Good results are obtained by filing grooves in the top of the cage and on top of the check valve, so that the possibility of a large percentage of the area being shut off by contact one with the other is not possible."

QUESTIONS.

222. Name the principal factors in the transmission of the steam from the boiler, to the cylinders of a locomotive, and from there to the open air?

223. What is the function of the steam dome?

224. Describe the old style throttle valve.

225. Describe in brief terms a modern throttle valve.

226. Describe briefly the route taken by the steam in its passage from the steam dome to the steam chests.

227. How is the steam admitted to, and released from the interior of the cylinders?

228. Is steam admitted to the cylinder during the entire stroke of the piston?

229. Assuming that the admission of steam to the cylinder is cut off before the piston has completed its stroke, what force acts upon the piston to push it to the end of the stroke?

230. What is the function of a steam gauge?

231. Is this a matter of much importance?

232. What type of steam gauge is the most reliable?

233. Describe the principle of this gauge.

234. What is one of the prime causes of boiler explosion?

235. What is a sure preventive of explosion from this cause?

236. Is the common, or lever safety valve reliable?

237. What are the requirements of a reliable safety valve?

238. Describe the action of a modern safety valve, or pop valve.

239. How may the valve be adjusted as regards the point at which it will open?

240. What precautions should be observed in the setting, and care of a pop valve?

241. What is a muffled pop safety valve?

242. What is superheated steam?

243. Upon what does the temperature of steam in contact with water depend?

244. Describe in general terms the method of superheating steam for locomotives.

245. Are there any advantages gained by the use of superheated steam?

246. Mention some of the principal advantages claimed for superheated steam.

247. In the Toltz superheater how are the superheater tubes protected from the heat when the engine is not working steam?

248. What are the advantages claimed for the Toltz superheater?

249. Is the heating surface of the boiler increased or decreased by the application of the Toltz superheater?

250. What two important advantages are claimed for the Schenectady superheater?

251. What new features are introduced in connection with this superheater?

252. Describe the course of the steam after leaving the dry pipe of an engine equipped with the Schenectady superheater.

253. How are the superheater tubes protected from excessive heat when steam is not being used?

254. Is there any loss in heating surface on a boiler equipped with the Schenectady superheater?

255. What is the average temperature of the superheated steam as it passes through the steam pipes on its way to the cylinders, assuming the boiler pressure to be 200 lbs. per sq. in.?

256. What is the temperature of saturated steam at 200 lbs. per inch?

257. What percentage in saving in fuel consumption is claimed for the Schenectady superheater?

258. What precautions must be taken regarding cylinder lubrication with engines equipped with superheaters?

259. What can be said regarding the feeding of water to a boiler in operation?

260. Upon what does the efficiency of a boiler depend in a large measure?

261. Theoretically what would be the correct way to supply a boiler with water?

262. Are these conditions practical?

263. What is the duty of engine men regarding the injector?

264. Is this an important subject?

265. When is a good time to use the injector?

266. How may the latent heat stored in the water be utilized?

267. Mention another "right" time and place to use the injector.

268. Should an injector have a wide range of capacities?

269. What can be said of the leading types of modern injectors?

270. Who invented the injector?

271. How can an injector lift and force water into a boiler under pressure?

272. What two important qualities does steam possess that enables it to do this?

273. When steam comes in contact with a body in front of it what is the tendency?

274. What is momentum?

275. What is the velocity in feet per second of a jet of steam discharging at 180-lb. pressure?

276. What is the function of the combining tube of an injector?

277. What are some of the requirements of this tube as to construction?

278. Why does the combined jet enter the boiler?

279. What is the velocity of this jet in the delivery tube?

280. What velocity does the jet need to enter the boiler carrying 180 lbs. pressure?

281. To what, then, is the action of the injector due?

282. What can be said of the Sellers' Improved Self-acting Injector?

283. What is its range as to pressures?

284. How is the size of an injector determined?

285. What is the capacity per hour of a number 9½ Sellers' at 200 lbs. pressure?

286. What are some of the things to be done in caring for an injector?

287. What about the Sellers' Self-acting Injector Class "P"?

288. What should be the quality of the steam used in an injector?

289. Suppose that an injector suddenly stops working, what are some of the probable causes?

290. And what are the remedies?

291. What sometimes happens to the lifting tubes?

292. Suppose the main check valve does not seat. What is to be done?

293. If there is an air leak in the suction pipe, what is the result?

294. What do lime and salts in the water do for an injector?

295. If the inlet valve does not feel cool, what is the matter?

296. What type of injector is the Metropolitan?

297. What function does the lifting set of tubes perform?

298. How low a steam pressure will the Metropolitan start with?

299. How high a pressure will it work up to?

300. Is there any waste at the overflow?

301. Is it easily regulated?

302. What is the capacity per hour of a No. 9 Metropolitan?

303. How is the capacity of this injector regulated?

304. What are some of the causes of this injector not working properly?

305. What are line check valves?

306. What can be said of the "88" Monitor injector?

307. How should it be located with reference to the water level in the tender?

308. What kind of combining tube has Rue's Little Giant Injector?

309. How may it be used as a heater?

310. What type of injector is the "simplex"?

311. What is its throttling capacity?

312. How is it used as a heater?

313. What is the range in pressures for starting the Lunkenheimer Injector?

314. What is the capacity per hour of a No. 15 Lunkenheimer at 200 lbs. pressure?

315. Of what does the Hancock Inspirator consist?

316. How high will it lift water?

317. Of what does the lifting apparatus consist?

318. How is the combining tube of the inspirator made?

319. What is the range of working pressures of the Hancock Inspirator?

320. At what pressure is its maximum capacity?

321. At how high temperature will it take feed water?

322. How is it regulated?

323. What is the function of the intermediate overflow valve?

324. What is the capacity per hour of a No. 9 Hancock Inspirator?

325. How should the inspirator be located in order to obtain the best results?

326. What is a frequent source of annoyance in the use of the inspirator?

327. Mention other causes for the instrument not working.

328. What is a "composite" inspirator?

329. Mention some of the characteristics of the Hancock "Composite."

330. What can be said of the water glass and gauge cocks, relative to the operation of a locomotive boiler?

331. Is it to be considered of as much importance as the steam gauge?

332. In case the water glass should not indicate the true level of the water in the boiler, what is likely to happen?

333. Mention the principal causes for the erratic action of the water glass.

334. Describe the proper method of connecting the top end of the water glass with the steam space of the boiler.

335. At what point relative to the crown sheet should the lowest visible portion of the water glass and the lowest gauge cock be located?

336. How long should the exposed part of the water glass be?

337. How many gauge cocks should there be, and what should be their vertical spacing, center to center?

338. What is the proper height for carrying the water in the boiler?

339. Mention some of the disadvantages that result from carrying the water too high in the boiler.

340. Is a fusible plug an advantage to a locomotive boiler?

AUTOMATIC WATER DETECTOR OR FUSIBLE PLUG.

In former years the fusible plug for detecting low water in the boiler was considered a necessity, but in these days of high pressures, it is losing its prestige as a safety device.

The rules of the United States Board of Supervising Engineers for steam vessels require a fusible plug, filled with block tin, to be placed in each furnace, at the highest point of the crown.

With locomotives, however, the conditions are altogether different. The intense heat in the fire-box renders all appliances of this character more or less unreliable.

The presence of the engineer and fireman continually in close proximity to the water glass and gauge cocks should give a close supervision over the water supply.

The consensus of opinion appears to be, that in locomotive practice, fusible plugs are absolutely unreliable, and should not at any time be relied upon to give indication of low water in the boiler.

A good water glass, properly connected and cared for, together with gauge cocks often tried, are the only trustworthy appliances for indicating the true level of the water in locomotive boilers.

In the Locomotive Firemen's Magazine (Nov., 1904, issue) Mr F. J. Cole, Mechanical Engineer of the American Locomotive Company, presents the following thoughts on the subject of fusible plugs:

Mr. Cole says: "A fusible plug or low water detector is not generally considered necessary or desirable, nor is it essential to the safety of locomotive boilers. Unless of good design and properly filled with metal which can be relied on to fuse at a uniform temperature, it will usually prove to be worse than useless. Reliance may be placed on it and vigilance in maintaining the proper level of water relaxed under the supposition that the presence of a fusible plug will be in some degree a guarantee against low water and its usual accompaniment of an overheated crown sheet.

"For this section of the country fusible plugs are applied to locomotives built by the American Locomotive Company only to comply with the Massachusetts State law, which requires their use. Railroad companies in very few cases, of their own free will, require their application. Owing to the extreme heat of the fire-box and the variable conditions incident to the use of locomotives, a fusible plug, to be of any value whatever, must have very little surface exposed to the heat of the fire on the lower side of the crown sheet. This necessitates a small, thin hexagon head. The body should project above the crown sheet about 1⅜-inch to keep the fusible metal well under water, away from the hotter crown sheet and in order not to unduly reduce the water level and leave the crown sheet bare in case of melting. Print 661-A-1000 shows a good design of fusible plug."

Owing to the increase of steam pressure to an average of, say 200 pounds, the melting temperature of the filling requires to be higher than pure tin. Saturated steam of 200 pounds pressure has a temperature of 387° and the melting point of pure block tin is 421°. This margin is evidently too small. It is necessary, therefore, to fill them with either a composition whose melting point is between 500° and 600°, or use pure lead, which has a melting point of 594°.

The experience of one large railroad operating over a thousand engines was that unless fusible plugs were renewed every thirty days, they became very unreliable and could not be depended upon. After a newly filled plug is inserted and the engine put into service, the filling will commence to melt out from the bottom to slightly above the top of crown sheet, owing to the heat being conducted by the head from the portion which goes to the heated fire-box before it is sufficiently reduced by the surrounding water.

The tendency, then, is for the hole to fill up with a hard accumulation of soot or burnt refuse product of the fuel. This, in time, may entirely fill up the opening, especially if small. A hard scale frequently forms on the upper end. This can become so thick and hard, and by penetrating into the pores and crevices of the fusible metal as it partly melts and becomes somewhat porous or minutely honeycombed so as to change very materially its nature and reliability to melt at a given temperature.

Only a small percentage of the engines built at the Schenectady works of the American Locomotive Company during the last three years have been equipped with fusible plugs.

Standard practice of this company in this respect for use at all works is as follows:

"Fusible plugs are not to be applied to fire-box crown sheets unless distinctly specified.

"In cases of duplicate orders raise question.

"If specified, and of no particular design, use Card 661-A-1000.

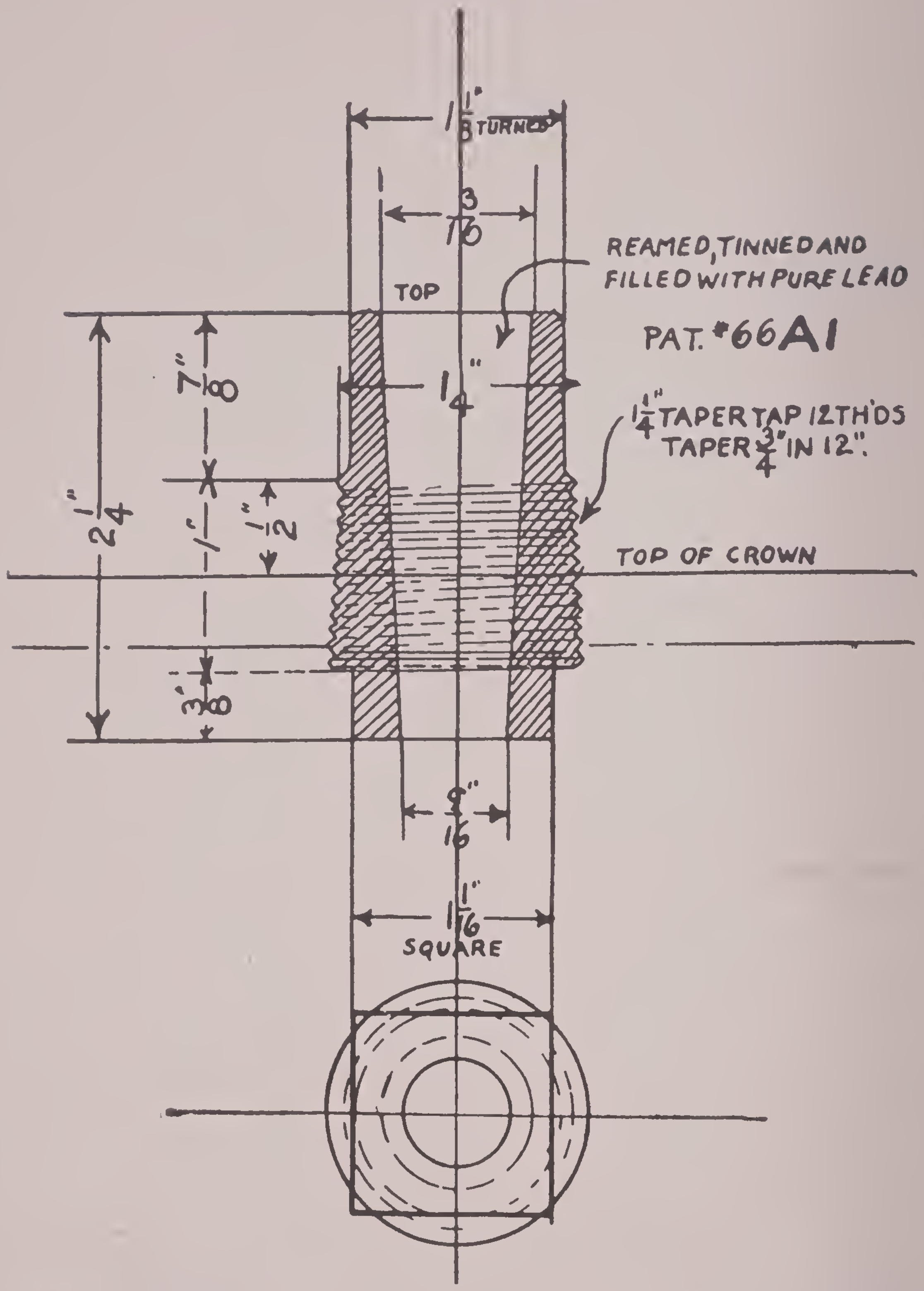


Fig. 148. Fusible Plug (Print 661—A—1000)—American Locomotive Co.

"*Exceptions:* All locomotives operating in Massachusetts must, according to State law, be provided with fusible plug."

MISCELLANEOUS.

The remaining pages of this volume will be devoted to a discussion of various miscellaneous matters pertaining to the care and operation of locomotive boilers.

ELASTIC LIMIT IN BOILERS.

The physical condition of metals under long continued strain, where the stresses are well under the elastic limit, is not as well understood as it should be, when the importance of such information is considered in connection with the use of boilers. The effect of vibrations in bridges under load is shown by test in the crystallization of the material due to the dynamic forces, a result to be inspected, but in the case of boilers in which the steam pressure is not allowed to exceed a figure for which the boiler is designed, the supposition is a natural one that there can be no forces at work tending to deterioration, provided the feed water is pure. In boiler design it is not uncommon to stress the material to not more than one-third the elastic limit, with the theoretical assurance that permanent deformation cannot occur. Age is a factor, however, that has been recognized in a perfunctory way, and it is the practice on some roads to dull the tooth of time by a reduction of steam pressure every five years, by an increment supposed to amply cover weakness due to advancing years.

According to the Mechanical Engineer of London, tests have been made on plates doing duty in a boiler constructed in 1859, a boiler which had never been unduly strained, and which had been fed with pure water. The results of many tests of the plates from this boiler revealed a want of elasticity in the material, supposedly due to the long life under pressure. Those who were interested in the tests formulated the proposition that a boiler should be taken out of service after a life of thirty-five years, notwithstanding it gave no sign of failure. This boiler was in service during a period of forty-five years, and should have been scrapped years before, by the evidence of the tests, but why this age limit should be given as above, there is no data. There is, though, no doubt, that reliable information on the ravages of time and stress on boilers is needed in this country. If such were available to draw from, there would be fewer occasions to record mysterious boiler failures.—Railway and Engineering Review.

DECLINE IN LOCOMOTIVE BOILER PRESSURE.

From present indications, it appears that builders and users of locomotives have arrived at the conclusion that the limit has been reached in high steam pressures, and a gradual decline in the same has set in. The following interesting discussion of this topic is reproduced from the Railway Age:

"The maximum working pressure for locomotive boilers has been gradually increased with the general trend of enlarged proportions and the demand for greater power. In the United States this pressure has been nearly doubled in the past 30 years, which is within the active working period of many of the officers now connected with the locomotive department of our railroads. For some years prior to 1880 the standard boiler pressure on many roads was 125 pounds. In 1885 150 pounds was used by the more progressive lines, and in 1890 160 pounds was quite generally used. In 1895 the pressure had increased to 180 pounds, and in 1900 200 pounds was tried by a few roads, and since that time it has become quite generally introduced. While some roads have gone as high as 210 to 220 pounds, there are now seen signs of a decided change, making 200 pounds the limit, with a tendency to go below that rather than above it.

With boilers well constructed and good water it is possible to work locomotive boilers successfully at 200 pounds pressure, but these conditions are not found on many railroads in the United States, and there is at present a well sustained opinion that high boiler pressure has been responsible for many of the boiler troubles which have been so generally complained of in recent years. For shell boilers with fire tubes and staybolts, 200 pounds appears to have overreached the mark for successful operation. Where pressures exceed 200 pounds, as in marine service, there is a tendency to use water tube boilers, and designs for this type of boiler for locomotives are gradually coming out. In the recent exposition at Liege, in Belgium, a locomotive, with a water tube boiler was exhibted.

The present boiler in the locomotive testing plant at Purdue University was designed for 250 pounds pressure, and it was built with special care. After 30,000 miles running the fire-box side sheets required renewal, and the leakage of tubes, staybolts and mudring has been of constant occurrence, while the effect of incrustating solids in the feed water has seriously affected the operation of the plant at high pressure. The previous boiler, which was worked under lower pressures, gave little trouble from any of these causes. Dr. Goss, who has been conducting some research work on high boiler pressures, has already reached the conclusion that the attempt to increase beyond the present limits now common in steam pressure upon American locomotives can only lead to disappointment. The possible gain is small and is likely to be more than neutralized by increasing leakage, while the difficulties of maintenance and operation multiply. He says further that it is not improbable that the final results will show that 200 pounds, which is a generally accepted standard of today, is, in our western country, too high for best results."

The larger experience with high pressure boilers in actual service on a number of western roads has led to a similar conclusion. The Rock Island system has adopted 185 pounds as the standard boiler pressure for all classes of locomotives, with the exception of the Pacific passenger, which carries 200 pounds. The committee on standards for this system recommended a reduction of maximum steam pressure from 200 to 185 in order to reduce boiler repairs. In Germany, where steam and fuel economy in the operation of the locomotive has been given the most careful theoretical investigation, the compound engine was developed in order to use high pressure steam to advantage, but the successful experiments with superheaters on locomotives have led to the use of this improvement in connection with simple engines and lower boiler pressures. This is referred to in a very suggestive paragraph in Mr. H. H. Vaughn's paper on superheated steam, in the proceedings of the last Master Mechanics' convention, where he says:

"A possible advantage of superheating has not been utilized in application in America, namely, a reduction in boiler pressure without loss in efficiency, although in Germany this has been usual. There is no doubt that the increase of pressure from 175 to 200 and 210 pounds that has taken place within the last few years has been of doubtful advantage. While there is a gain in economy, this is accompanied by an increase in the losses due to leakage, both in engine and boiler and by a considerable increase in the cost and trouble of boiler maintenance. By superheating, the initial pressure becomes of less importance, and with the proper amount of superheat it will be possible to return to pressures of 175 pounds or less, without any appreciable loss in economy, and with a relief from those boiler troubles, which have become more serious as the pressure has increased, it is probable that the saving from this cause alone will overbalance any additional expense connected with the maintenance of the superheater."

There is a difference of only three British thermal units in one pound of saturated steam at 175 and 200 pounds gauge pressure, and the difference in steam consumption is only two pounds per indicated horsepower hour in simple locomotives. The slight gain in economy due to the higher pressure has in most cases been more than balanced by greater leakage and the increased cost of boiler repairs. It is safe to say, then, that the only advantage which railroads have gained by the use of boiler pressures of 200 pounds, or over, has been increased power in the engine. If this can be obtained without the disadvantage of frequent engine failures, it is worth while, and it is a sufficient reason for using the higher pressure. The net result, however, should be measured by the number of ton miles per month or year, and if engines carrying the higher pressure are laid up in the shop or roundhouse for repairs a longer time than those carrying a lower pressure, it is quite possible that the latter may haul a larger tonnage per year. The records of railroads should show what this difference is, and it would be interesting and instructive if some railroad which has reduced its boiler pressure on freight engines from 200 pounds to 185 pounds should compare the total tonnage and cost of repairs per year for the same engines under the two different conditions of boiler pressure.

WIDE FIREBOXES FOR LOCOMOTIVES.

Railway Master Mechanic.

The fact that the length of grate for locomotive boilers had reached the maximum for stoking by hand was realized some years ago, but it seems that it was only the conditions for burning anthracite coal that furnished the necessary urgency for developing the wide fire box. At all events, the large grate surface was developd first for anthracite coal.

A very good reason why the large grate area was used first for anthracite coal was that the large grate was really necessary for the successful burning of this fuel, particularly so because the intention was to use as fuel the large accumulation of what was then the refuse of the mine, by such railways as had this fuel convenient to their lines and did not have bituminous coal equally as convenient. In a word, there was the strong incentive—in fact, the necessity—of developing a fire box in which such fuel could be successfully used. Although efforts were made to use the large grate surface with the softer coal, there was lacking a sufficiently strong incentive to justify a study of the question with the seriousness necessary to insure success.

Efforts were made to burn bituminous coal on large grate surfaces, but, as success did not come with the first trials, many men thought to profit by the experience of the few and continued to build fire boxes limited in width by the spread between driving wheels. It may be appropriate to explain, in a word, that the conclusion to avoid the wide fire box was probably influenced quite as much by the failure of faulty boiler designs (which designs have been improved since, as dictated by experience) as by failure in steaming qualities.

Until the more recent rapid increases in heating surface, the grate surface of locomotives using soft coal was not so prominently deficient, and any increase in demand for heat was met by an increased rate of combustion. Of course, this meant a decrease in the rate of evaporation, but it was necessary for a certain degree of tension to develop to justify radical departure from firmly established practices. This degree of tension has resulted from increased weight of trains and increased speed, demanding larger heating surface to supply the amount of steam required. The heating surface has, accordingly, increased at a rapid pace in more recent years, until it has become necessary to concentrate attention on the fire-box with the purpose of providing a grate surface, and as there has been developed, first a means of increasing the width of the fire box, we have the wide firebox locomotive and the radical departures in designs made necessary by the use of the wide fire box.

It is quite possible that a means may be provided for stoking by machinery a longer grate than can be properly stoked by hand, and if this develops it is reasonable to presume that this method will be favored.

The wide fire-box is necessary for large grate surface and hand stoking, and in providing the large grate there seem to result incidental advantages which will be quite material as follows: The fire box temperature will be less intense, and, therefore, the fire-box sheets may be expected to deteriorate less rapidly; with the decreased length of fire box the service of the stay bolts should be improved.

The wide fire box works in very nicely with driving wheels as large as 63 inches over tires and a boiler as large as 72 inches in diameter, giving a throat of reasonable depth, and placing the boiler not too high for stability for locomotives with three, four or more pairs of driving wheels. Designs have been proposed for wide fire boxes over large diameter driving wheels, but it is questionable whether such would work to entire satisfaction with soft coal. The recent designs of locomotives with wide fire-boxes for bituminous coal and large diameter drivers, have used a pair of carrying wheels 50 inches or 52 inches in diameter under the fire box, driving wheels forward of the fire-box, and either a 2-wheel or 4-wheel leading truck. With three pairs of drivers, such designs require a long tube, and, if we anticipate a month or two, we may say that the 20-foot tube has been reached. With, however, many pairs of drivers located ahead of the fire box, the trailing wheels must carry the fire-box, and already we have reached what seems to be about the limit of weight on one pair of carrying wheels.

CAUSES OF INJECTOR TROUBLES.

Engineers sometimes experience considerable difficulty in finding the cause for the failure of the injector to work properly and oftentimes attempt to interfere with the interior of the injector. When making pipe connections, it is necessary to blow out the pipe clean before connecting the injector, in order to remove all red lead, scale and other substances that may be in the pipes and which would otherwise fill the nozzles of the injector and impair its operation.

After the connections have been examined, and if found in good order, the injector is disconnected and the cap or plug removed for the purpose of cleaning the nozzles. As a rule, when the injector fails to lift water probably the difficulty is with the suction, which must be absolutely air-tight. Another cause of failure is the overflow. When the latter is choked or badly piped up, and is not wide open, the steam and air do not have free vent, and will not let the water rise in the suction pipe. When the water supply pipe is very hot, it should be cooled with cold water, or by turning the steam on and off suddenly at the starting valve, until the hot water is disposed of.

When the lift is out of proportion and is too high for the steam pressure, and, too, when the steam pressure is alternately too low and too high, as well as a lack of water, will also cause an injector to fail. The strainer also may be clogged up, and when an injector will lift water, but will not force it into the boiler, the trouble is generally caused by not giving enough water. A defective check valve in the delivery pipe may be stuck down, or is not set properly and gives insufficient rise or lift, or a leak in the supply pipe, admitting air to the injector, or the delivery nozzle may have become dirty, and need cleaning; all these things tend to produce failure of injectors.

When the injector starts properly, but breaks the vacuum, it indicates that either the supply of water is not properly regulated or a leak exists in the supply pipe or that the disk of the steam valve is loose. Connecting the injector steam pipe to pipes used for other purposes also causes numerous difficulties which are oftentimes hard to locate.

To prevent an injector delivery pipe from freezing in very cold weather the following plan may be pursued—

By using the heater, having the steam valve slightly opened, with the overflow valve closed, steam will flow back into the tender through the feed pipe and at the same time flow forward into the branch pipe. The heater cock should be opened to drain the condensed steam or water from the delivery pipe, otherwise it will fill with water and freeze. The steam valve should not be open so far as to cause water to become overheated in the tender, preventing the injector from working or damaging the paint on the tender.

The following thoughts on injector connections are here reproduced from the American Engine and Railroad Journal—

"It is not unusual for a large locomotive injector to throw 3,500 to 4,500 gallons of water into a locomotive boiler in an hour and yet such delivery is expected to be provided for through pipes no larger than were formerly used in connection with injectors which would deliver but 2,000 gallons in that time.

"While great progress has been made in connection with other parts of locomotives, the injector connections have not been given the attention which they deserve and the locomotive has fairly outgrown them. In many cases the old standards have remained the same for about twenty years, notwithstanding the fact that locomotives have been more than doubled in capacity in that time. With increased boiler capacity and high steam pressure it is necessary to use injectors which will deliver a great deal more water than that which formerly sufficed, and the time has come for a radical change in this practice.

"There seems to be no reason why at least 3-inch smooth-bore hose should not be used to connect with the tender tank. With this a free opening of 2⅝ inches may be obtained in the fitting. A strainer at the valve in the tank well may be used and the conical strainer in the pipe removed. This would permit of using much larger channels for the water to the great relief of the injectors.

"It is not enough to enlarge the suction side alone, the delivery pipes and checks also appear to need attention. The duplex check fitting supplied by the Brooks Works, which is shown in many locomotive engravings in this journal, seems to be a very good device, because it delivers all the water on one side of the boiler, which seems to be better practice than to enter it in two places and in two directions. This, however, is not the main point of this criticism. The free and unobstructed opening for the water is what is needed. A check that will lift but 1-16 inch for a No. 10 injector connected by a 2¼-inch pipe is not sufficient, yet this has been found in a recently built locomotive. Such an injector needs at least an even equivalent to a 2-inch hole. In one of the reports presented to the Master Mechanics' Association last June the following suggestions occur:

"As the water evaporation is heavy, a good inlet from tank to injector should be provided. A majority of the manufacturers prefer the following sizes of feed-pipe in connection with the different-sized injectors:

"No. 8, not less than 2 inches internal diameter.

"Nos. 9 and 10, not less than 2½ inches internal diameter.

"Nos. 11 and 12, not less than 3 inches internal diameter."

Cleaning Flues. The entry on the round-house work book of "Bore out flues," generally results in two men getting on the engine with one long and one short "flue auger." With these two "pokers" the two men are enabled to spend two to four hours ostensibly at work, but in the matter of desired results very little indeed is accomplished. The use of compressed air for blowing out the tubes is rarely undertaken because of the impression that a too great quantity would be needed. The use of steam is disagreeable because of its heat. On actual trial of compressed air, however, it will be found that not a great quantity is needed. The pump of one engine alone on an adjoining pit will furnish plenty of air, while the speed with which the tubes can be blown entirely free of the accumulation is surprising, as is also the number of solidly stopped tubes which can be freed by this means alone. Another commendable feature of this plan is that but one man is required for the work and that the foreman can easily keep track of his continuity of endeavor, for his cessation of work is indicated by a cessation of dust coming out of the stack. The adoption of this plan at one terminal largely reduced the number of such reports, for it was found that well-cleaned tubes were not reported so often, while the ease and rapidity of boring by this method rendered the shop force less inclined to put off and slight the work. The contrivance used was simply a piece of half-inch pipe, with the hose attached to one end, the other end slipped six inches through a hole bored in a flue plug. A cutout cock was placed in the length of the pipe to enable the workmen to shut off the air while crossing the bridges in the tube sheet.

LUBRICATOR ACTING AS A SIPHON.

Sometimes it happens that as the boiler is cooled off, oil from the lubricator is siphoned into the boiler. The cause of this is explained as follows:

When a boiler is in service it contains water and steam at a temperature in proportion to the pressure. The steam and water occupy space. When allowed to cool the steam is condensed, and the water, losing its heat, also occupies less space. When this occurs a vacuum is formed in the boiler. Atmospheric pressure surrounding the boiler trying to get in and destroy the vacuum is the cause of the oil siphoning out of the lubricator, and this occurs only when the lubricator is not perfectly tight in all joints. A very slight leak at filling plug, around the gaskets of the oil glass, or packing nut on the feed valve, will admit air enough to destroy the vacuum and allow atmospheric pressure on top of the oil in the cup. The vacuum in the boiler will tend to draw the oil up through the steam pipe above the water valve when it is open, and as this passage or pipe extends nearly to the bottom of the oil cup it affords an easy passage for the oil to siphon into the boiler. If the oil cup was absolutely airtight oil would not siphon out. This is why it only takes place occasionally on certain engines when the lubricators are not absolutely tight.

HORSE POWER OF BOILERS.

The latest decision of the American Society of Mechanical Engineers (than whom there is no better authority) regarding the horse power of a boiler is as follows: "The unit of commercial horse power developed by a boiler shall be taken as 34½ units of evaporation per hour. That is, 34½ lbs. of water evaporated per hour from a feed temperature of 212° into steam of the same temperature. This standard is equivalent to 33,317 B. T. U. per hour. It is also practically equivalent to an evaporation of 30 lbs. of water from a feed water temperature of 100° F. into steam of 70 lbs. gauge pressure."

POUNDS OF WATER CONVERTED INTO STEAM BY HEAT OF ONE POUND OF COAL.

In ordinary locomotive practice from five to eight pounds of water are converted into steam by the heat of one pound of coal. Ordinarily, six pounds of water per pound of coal is an average.

A WATER-TUBE LOCOMOTIVE BOILER.

The illustrations, Figs. 144, 145 and 146 here shown are of a water-tube locomotive boiler which has been in successful use on the Algerian lines of the Paris, Lyons and Mediterranean Railway, and was built after the designs of Mr. J. Robert, the chief engineer.

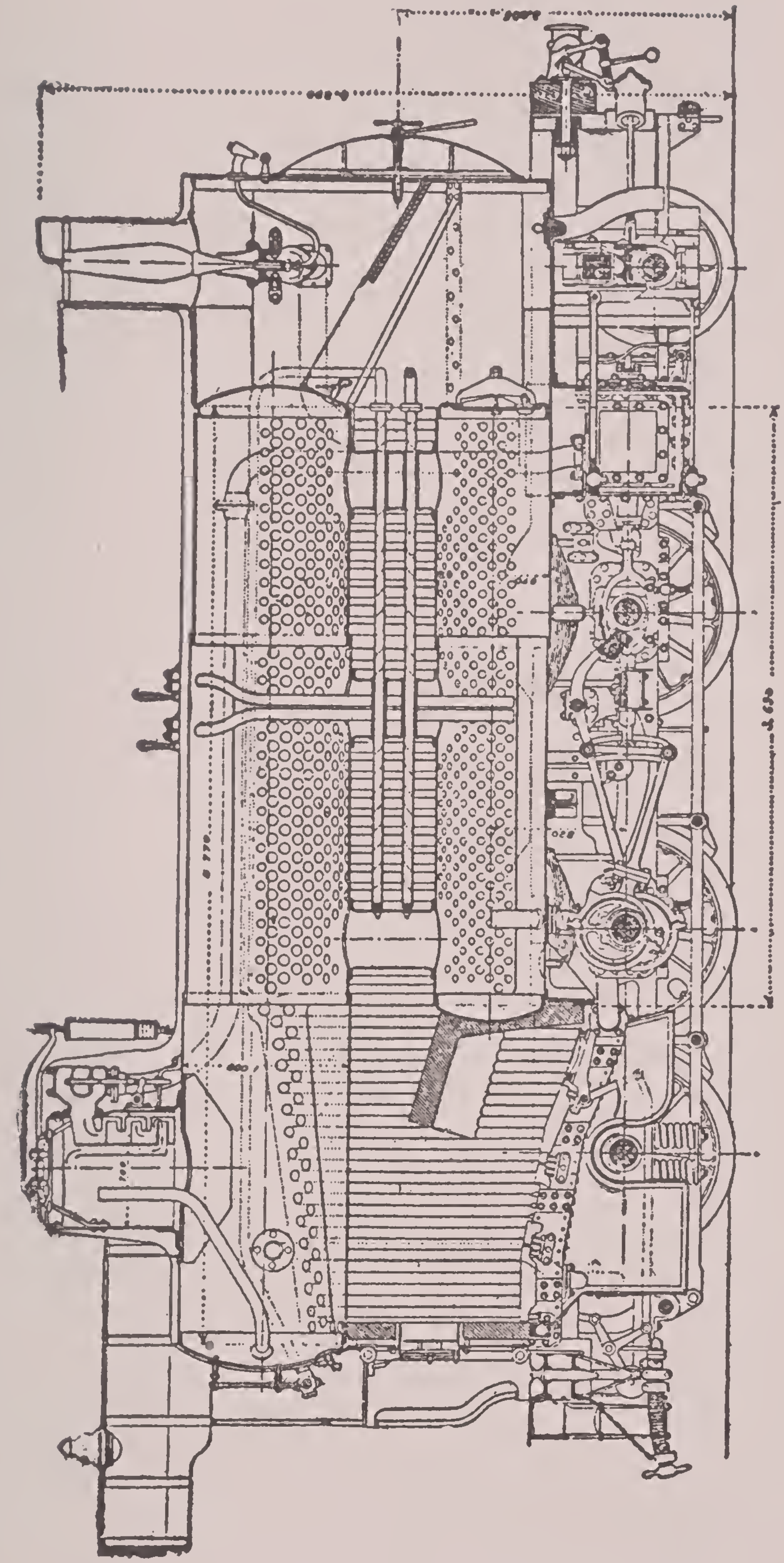


Fig. 144. Water-Tube Locomotive Boiler, Paris, Lyons and Mediterranean Railway—Longitudinal Section.

Within the boiler are two horizontal drums, the larger being above and the smaller below, which are connected by three upright tubes or pipes, as well as by the circulating tubes. The lower drum is filled with water, and the upper drum contains both water and steam.

The side walls of the fire-box are formed by a series of tubes which connect the upper drum with headers below the grate level, these headers also being connected with the lower drum by circulating pipes. The gases from the fire-box pass between the nests of water tubes on their way to the smoke-box.

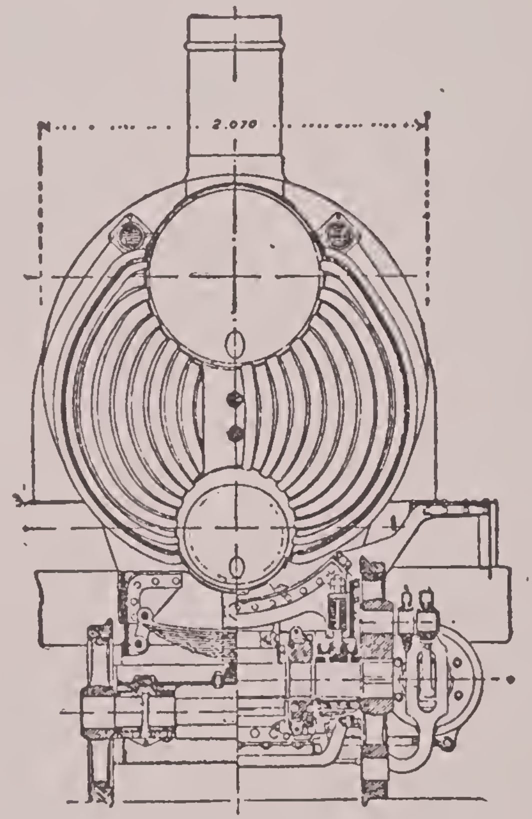


Fig. 145. Water-Tube Locomotive Boiler—Cross Section.

This boiler is said to have special advantages over the ordinary boiler in the ease with which it may be cleaned, no flat surfaces to be stayed by bolts or braces, less weight for the same amount of heating surface, and less time required for making repairs.

HOW TO MAKE LIGHT REPAIRS ON THE LOCOMOTIVE BOILER.

The boiler has arrived at that stage when it is necessary to remove all of the tubes, if they are close together, say, ½ in. to ⅝ in., this will be from two and a half to three years after engine was put in service; should they be ⅞ in. to 1 in. apart, it will be three and a half to four years, provided that the boiler is using the ordinary run of water. Should the feed-water be such that considerable scale is formed of a hard, stony nature—impervious to water—the life of the tubes between settings will be shortened from six to eight months.

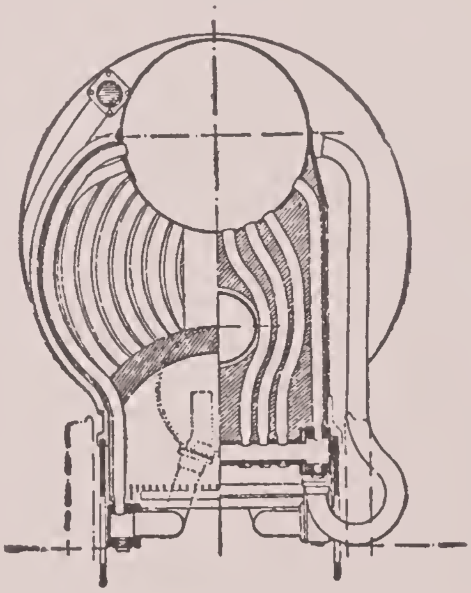


Fig. 146. Water-Tube Locomotive Boiler—Cross Section.

Rainy seasons also shorten the life of tubes between settings, especially in boilers in which scale has formed to a considerable extent.

The soft water loosens the scale which has formed on the tubes and it is lodged between the tubes; at every successive rain more scale is loosened and lodges between the tubes, until finally all the space is filled up, making the removal of tubes necessary.

The usual method of making repairs at this time is to remove tubes, make a cursory examination of the external portion of the shell—if lagging is removed—and caulk all leaks. If any stay bolts are broken they are renewed, a few rivets taken out of mud ring and replaced with new ones, and seams in fire-box caulked where necessary.

If stay bolts and radial stays or crown-bar rivets are not leaking (they should not be if boiler has received proper care), no attention is paid to them. The mud and loose scale is thrown out of the boiler, it is given a rinsing, the tubes are replaced, and the boiler is "just as good as new" and ready for service. This is by no means an exceptional way of making repairs.

When a boiler needs no other repairs than the changing of tubes the greatest amount of labor should be put on the inner part of the boiler. You will want your best man to do it, not necessarily the best mechanic, but a man with patience, endurance and perseverance, plenty of stick is what is needed. Furnish him with all kinds of cleaning rods, a scaling pick, hammer and chisel, a few torches made of ⅛ in. steel wire, wrapped at one end with asbestos, and a can of oil to replenish torch; can should have neck large enough to allow the insertion of torch. Have all the scale cleaned from sides of water leg, stay bolts, crown sheet, crown-bar washers, crown bars and shell. Do not expect to have the labor performed in a few hours; it will take five or six days to do it properly. When the scale has been loosened, the boiler should be thoroughly washed; this cannot be done properly in an hour or two, but will take six or eight.

As all parts of a locomotive boiler are not open to inspection it is impossible to keep all parts cleaned alike; you may find here and there the water space nearly filled with scale, and, although it has made no trouble, the trouble was not far off.

The cleaning process should be begun at the lowest part of water space and continued toward the top. Especial pains should be taken with the inner end of stay bolts, inner side of water leg, crown sheet and crown-bar washers, as these are the parts that make trouble on account of scale formation. The bottom of shell should also be cleaned thoroughly its whole length and about thirty inches wide in order to ascertain its condition in regard to pitting and grooving. As a rule, the shell will be pitted most just below the checks; the pits are not readily discovered, and must be cleared out with a chisel. If guide-yoke or frame-brace angles are fastened to shell with either rivets, studs or tap bolts the pitting is invariably worse around these than elsewhere. The pitting and grooving of shell should not be dangerous at this time.

All braces, brace pins, brace lugs, crows feet and angles should be thoroughly inspected. If the boiler is sufficiently braced, these should still be in good condition. However, this should not be taken for granted, as the safety of life, limb and property depends as much on good, sound braces as on sound stay bolts.

It may be that the brace lugs and crows feet, instead of being forged from the solid bar, are made of two pieces jumped together, and that some of these are pulling apart in the weld. They should be removed and replaced with braces forged from the solid bar. Should back tube sheet have crow-foot braces riveted solid to tube sheet, they should be taken off, holes in pad or flat end welded up, a piece of 1-in. pipe 1 in. long put between brace and tube sheet, new holes drilled in pad and braces reriveted. This manner of bracing allows the water to circulate between brace and the tube sheet, keeping the sheet cool and preventing cracking and distortion around the rivet holes.

THE BOILER BENDS IN SERVICE.

The frames of the locomotive are regarded as two girders, and are supposed to be strong enough to bear the weight of the boiler and all that is on it without yielding, but this is not entirely correct.

The boiler and frames are secured to each other by the expansion braces at the fire-box end, the cylinders at the front end, and by belly braces at intermediate points along the barrel of the boiler. The boiler and frames being bound to each other in the manner they are, it is the supposition that that combination is self-sustaining, but such is not the fact, as the boiler itself indicates. Keen observers, who are responsible for the care of boilers, know that the boiler yields by its own weight when it receives heavy shocks. Where the belly braces are riveted to the barrel of the boiler, which has run any length of time, it will be found that around the edge of the rivets, inside the boiler, the sheets are grooved. Grooving is nearly always a result of sheet movement. If these braces are not riveted, but are brought up to the boiler so as to fit around the under side, the working of the engine will show the chafing of the braces on the boiler, indicating the resistance it must offer.

Other signs of destruction are the small cracks that take place in the upper side of the throat sheet. These are generally supposed to be effects caused by some obstruction to the expansion of the boiler. When the upper corner stay bolts and others next to the flange of the throat sheet are found leaking, it is evidence of the strain put upon them when the boiler bends up or down. There is some spring between the flange and these stay bolts, but little or none in the upper sides, where the cracks take place. This spot may be looked upon as the fulcrum of the lever, as it receives the direct crushing effect, alternating as the boiler bends. The weight of the barrel and its contents, with the cylinder bolted to the smoke box, acts like a weight on the end of the lever, keeping that end of the boiler down and binding it to the frames.

These destructive strains mentioned may be regarded as mechanical while at the same time there are still some serious strains caused by the unequal expansion and contraction, due to heating and cooling. We have heard it said that certain boiler explosions were due to the act of God, but as a rule the neglect of inspection and proper reports by the men in charge are the real origin of the disaster.

EXPLODING BOILERS FOR KNOWLEDGE SAKE.

A series of experiments with boilers were made by the United States Government years ago that gave very valuable data about boiler explosions. One of the experiments was with flat-stayed surfaces that would very well represent side sheets or crown sheets secured by stay bolts. Heat was applied with plenty of water over the heating surface until the vessel exploded from over pressure. Dr. Coleman Sellers, who was present, describing this explosion, wrote: "It was fired up, and when the steam reached 125 pounds we left the boiler and retired to a safe place. In about five minutes, with about 180 pounds gauge pressure, it exploded. The sheets went out in the form of dishes, each part where the stay bolt was presenting an indentation like a mattress. Every stay bolt was drawn out of its hole. No stay bolt was injured in the slightest degree on its thread, but every hole, from which a stay bolt was drawn, was enlarged sufficiently to allow the stay bolt and its head to come out."

This is information worthy of consideration by people who act as experts before the courts when boiler explosions happen. The writer was present at a law suit once over an exploded boiler, and the attempt was made to prove that the accident was caused by low water. We heard several so-called experts testify that the sheets must have been hot because the stay bolts were pulled through the sheets without tearing off the threads.

LOW WATER SELDOM CAUSES EXPLOSIONS.

The belief exists among many people that a boiler will not explode so long as it contains a good supply of water. Properly conducted experiments have repeatedly disproved the correctness of this theory. An easily made experiment is: Take a piece of steam pipe 3 ins. diameter and 3 ft. long. Screw a steam tight cap on one end and put water in the pipe till it is two-thirds full. Then drive a pitch-pine plug into the other end until it is within 3 ins. of the water, giving room for expansion. Put the pipe on a bright fire and get out of the way, for an explosion will follow in a few minutes. If all the water was converted into steam there would be no violent explosion. The violence of a boiler explosion is directly in proportion to the amount of water ready to flash into steam when a rupture is made great enough to suddenly release the pressure.

The Pennsylvania Railroad Company, years ago, carried out a series of experiments with locomotive boilers that prove most of the statements made. A locomotive which was condemned to be scrapped, was run out on a side track in the woods near Altoona, and experiments made upon it. The plan was to fill the boiler with water, raise a high pressure of steam, then run off the water until the crown sheet was exposed, permit it to become red hot and then pump cold water into it, to find out the effects. In the first experiment the boiler exploded before they had time to blow off any of the water. They then took another old engine whose boiler stood the steam of unusually high pressure. After steam was raised the water was drawn off until it was below the crown sheet. They waited long enough for the crown sheet and the upper part of the fire-box to become red hot, then they forced a supply of water into the boiler by means of a powerful fire engine, and nothing happened except that the seams leaked and the steam went down. This was repeated several times, always with the same result. The boiler was damaged by the overheating, but no accident happened.

VELOCITY OF STEAM.

The utility of high-pressure steam as a means of transforming heat into mechanical work results in a great measure from its expansive force, and the velocity and freedom with which steam passes from one vessel to another or out into the atmosphere. The velocity of the flow of steam depends directly upon its pressure, and is as the velocity of a body falling freely by gravity from a height equal to a column of steam represented by the steam pressure, or to the difference of level between the height of the column of steam and the height represented by the pressure of air or other vapor into which the steam is passing. One exception to this is that the velocity of steam flowing into a vacuum is constant at all pressures.

To calculate the velocity with which steam of any given pressure passes into a medium having a pressure equal to the atmosphere, the following process may be followed: The required height of the column of steam is estimated by its proportion to a column of water due to a certain pressure. The square root of the height multiplied by 8, that well known rule regarding falling bodies, gives the velocity of steam due to the pressure. Suppose we wish to find out the velocity of steam of 10 lbs. pressure above the atmosphere. It is well known that 1 lb. of pressure represents a column of water 2.3 ft. high, and 10 lbs. pressure will represent a column of water 23 ft. high. At that pressure above the atmosphere, 1 lb. of steam occupies 1,008 times the volume of a pound of water. So $23 \times 1{,}008 = 23{,}184$ the height of the column of steam. Then $\sqrt{23{,}184} \times 8 = 1{,}218$, the velocity in feet per second of steam of the pressure given. A small fraction is omitted, but the result is correct enough for practical purposes.

The quantity of steam of any pressure that will pass out of a safety valve, a whistle slot or other opening can be calculated by this rule; but it is found that when the opening is made in a thin slot the escaping jet of steam suffers a contraction, so that its area is reduced from 30 to 50 per cent.

To calculate the velocity with which steam will pass into a cylinder or other vessel that is already filled with vapor above atmospheric pressure, the difference between the two pressures has to be taken. Suppose we have a steam chest pressure of 100 lbs. above atmospheric pressure, and at the beginning of the stroke there is a back pressure against the piston of 35 lbs. due to compression. The question is at what velocity will the steam begin to pass from the steam chest to the cylinder. Deducting the lower pressure from the higher one will give a basis for a column to generate the velocity. The velocity of steam passing from any higher to a lower level may be found at any point by this process.

PROMOTION FOR THE FIREMAN.

This is a topic that always is or at least always should be uppermost in the mind of any young man who has started in as a locomotive fireman, or as a helper in the round house, or machine shop. The subject of promotion of firemen, and the making of efficient engineers is one also to which much thought is given by the master mechanics, and other officials connected with the motive power of all successfully managed railroads. The following timely thoughts on the "Future Engineer" are from the pen of Mr. John M. Lynch, Traveling Engineer for the C. G. W. Railway. They were published in the April, 1907 issue of the Railway Master Mechanic, and are here reproduced. Mr. Lynch says:

"From my experience I would say that the best way to increase the efficiency of enginemen is to increase their confidence in the road they work for. The road foreman of engines or traveling engineer should be a man competent to instruct and get good work out of men who are willing to take advantage of his experience.

To bring about this closer relationship road foremen of engines or traveling engineers should not be required to assign enginemen to runs or to discipline them for infraction of rules. It might be all right for the road foreman of engines or the traveling engineer to make recommendations in this line but he should not be expected to carry them out himself as his usefulness depends largely upon the good feeling that exists between him and the men from whose ranks he has risen. He is continually with the men and is looked upon as their instructor and their advisor. They tell him their troubles and he knows all the difficulties they have to contend with, but if he is in a position to grant favors or discipline the men, they soon begin to regard him more as an informer than as a man who is there to help them increase their efficiency and thereby gain advancement, and they are less liable to receive his instructions in the right spirit and profit by them. When the enginemen look upon the road foremen of engines as their friend who will act as intermediary between them and their superior officers in times of trouble and who is doing all he can to make them more competent they will seek and follow his advice and then if he is the right man in the right place he will in time make competent men out of the most of them.

In considering various methods of increasing the efficiency of engineers, it is well to give a great deal of thought to the question of firemen, for these men are the future engineers. Our firemen are taken from the ranks of young men who are employed to work around roundhouses at cleaning fires, ash pans, wiping engines, firing up, or any other duties that may be assigned them. For this work we try to hire bright, likely young men with fair educations. As a rule they remain as handy men in the roundhouses from one to two years. For this work they are paid about $40 per month and are given to understand that if they prove competent, they will be promoted to firemen.

Forty dollars a month may seem small pay for what these young men do, but a close study of the situation will prove that a man who will work for from one to two years for this pay because he is ambitious to become a fireman has the right stuff in him and will make a valuable man on an engine.

There have been instances where we have hired young men with college educations and sent them out to learn to fire, but this class of men soon become satisfied to try some other work when they discover that firing is no snap, while the men who have gone through the roundhouse know what hard work and small pay are, and when their ambition to become firemen is realized they go at it with a will and a determination to earn further advancement."

Another advantage of making a practice of promoting men from the roundhouse is that every man that starts there at the bottom feels that if he shows himself competent, he will be promoted and that some outside man with no experience will not be put in to fire over his head. This also does away with the demoralizing effect that bringing in men from the outside to learn to fire has on the men who have been laboring faithfully at small pay just for the opportunity of promotion.

BRIQUETTES AS FUEL FOR LOCOMOTIVES.

In determining the best method of preventing the waste of our fuel supply, the United States Geological Survey has found that a valuable aid to this end will consist of the briquetting of fuel.

"Briquette" is the name given to a prepared fuel made of slack or waste coal, of peat or of lignite, held together by a bonding material, such as pitch, the mixture being pressed into a compact mass, of a size and shape suitable for use as a fuel. Briquetting is the latest and most satisfactory method yet devised for utilizing the waste from mines.

The tests which have been conducted at the Government Fuel Testing Plant at St. Louis, Mo., during the last two years have proved so satisfactory, that they are to be continued with even more vigor this year at the new plant at Norfolk, Va., where the briquettes will be burned in naval vessels in order further to demonstrate their efficiency, not only as steam producers, but as an admirable smokeless fuel.

While the primary object of the United States Geological Survey has been to find the best utilization of the fuels used by the government, the entire country cannot help but profit by the results of the investigations. These tests have enlisted the interest of manufacturers and others for they have resulted in the opening to the commercial world of a hitherto unknown field which it is thought is destined to become an important factor in the production of fuels.

Within the last six months, eastern and western capitalists have begun the erection of briquetting plants in North Dakota, Washington, Michigan and Missouri, their purpose being to manufacture briquettes from coal waste, lignites and peat.

The successful developing of the coal-briquetting industry in the United States depends upon a number of conditions that are expected to work out well in the future tests. The present drawback to such an industry is the low price of bituminous coal and especially the small difference between the prices of lump coal and that of slack or fine coal.

With anthracite and semi-anthracite coals, the difference between the price of lump coal and that of slack is often more than sufficient to cover the cost of manufacturing briquettes. There can be no question that the manufacture of briquettes from some of these coals will be successful commercially. Concerning still other coals, it is claimed that the difference between the price of lump and that of slack is either just sufficient, or scarcely so, to cover the cost of briquette manufacture, but the fact that briquettes present certain advantages over the lump coal may enable them to command a sufficiently higher price to afford a margin of profit.

The most favorable outlook at the present time for the development of this industry is in connection with the use of briquettes in locomotives, and in domestic furnaces and stoves. It has not yet been demonstrated that, at anything approximating existing prices, briquettes can be manufactured for successful use in the ordinary power plants of the country.

The results of recent investigations have shown that on boilers requiring forced draft, like locomotive boilers, briquetting so increases the efficiency of the fuel as to more than cover the increased cost of making.

Another advantage claimed for this fuel in locomotives, and one that will appeal to the great masses of the people, is that the briquette is practically smokeless. When it is realized that the smoke from locomotives in railroad yards constitutes a large part of the smoke nuisance of the great cities, the importance of this fuel will be seen at once. For the purpose of speedily solving this problem the Government will conduct a number of tests in co-operation with the railroads of the country.

The Missouri Pacific Railroad, the Rock Island, the Illinois Central, the Burlington, the Pennsylvania and other railroads have been testing briquettes for some time with excellent results. The Missouri Pacific officials have reported that briquettes were used satisfactorily as fuel for locomotives in two tests made on runs out of St. Louis. The data obtained showed that the advantages gained were more than sufficient to cover the cost of manufacture. Although at the present time definite statements cannot be made in regard to the practicability of this fuel for locomotive use, it would seem that briquettes are suitable for fast passenger trains and where high speed is necessary in express service, or in any difficult work, such as climbing hills, where the efficiency from coal is demanded.

It is claimed that briquettes burn with a higher efficiency and with less smoke than coal, because they allow a better circulation of air, that the combustion is more complete and uniform, and they burn with more flame (owing to the added combustible material), and at higher temperature.

Perhaps the most important of the tests to be made at the Government Plant at Norfolk this summer will be in connection with the burning of briquettes under the boilers of naval vessels. Briquettes have been used successfully in the navies of France and Germany for many years, and our own ships often when on cruise in the Mediterranean, have used them with uniformly good results.

One reason for the increased efficiency is, that the briquette retains its shape until completely consumed.

Briquettes made from Indiana coal were used on an Indiana railroad last year in order to compare the efficiency with lump coal from the same mines. The briquettes showed an increased efficiency over the lump coal from twenty-five to forty per cent.

Briquettes were also made from West Virginia coke breeze (waste), with and without the addition of a small amount of raw coal.

The briquettes made by both methods were hard and burned well, and doubtless would make a good substitute for anthracite coal.

It would seem from these tests that this might open up an important industry which would utilize a waste product and produce a valuable fuel.

Some experiments have been conducted with culm, the waste from anthracite mines, and these have met with excellent results. Briquettes made from culm are now being tested by the Lehigh Valley Railroad in its locomotives, and so far they have been successful.

With the growing scarcity of anthracite coal, the vast amount of fuel that now lies unused at the anthracite mines, may in the future prove extremely valuable.

VELOCITY OF THE FIRE-GASES.

There are several practical objections to the air blowing through the grates like a hurricane. The high speed of the gases lifts the smaller particles of the fuel, and starts them toward the entrance of the flues, helping to begin the action of spark-throwing. Where they find a thin or dead part of the fire, the gases pass in below the igniting-temperature, or tend in spots to reduce the heat below the igniting-point, and go away unconsumed, at the same time making a cold streak in the firebox, chilling the flues or other surface touched, and starting leaks and cracks. Then the great volume of air has, under ordinary circumstances, to be heated up to the temperature of the firebox, and a considerable part of the heat produced from the coal has to be used up doing this before any of it can be utilized in steam-making. When a large volume of gas is employed it must be passed through the furnace and tubes at a high velocity, the result being that there is not sufficient time for the heat to be imparted to the water; consequently the gases pass into the stack at a higher temperature than would be the case if the movement of the gases were slower.

SAVING THE GRATES.

An important duty, which is never neglected by first-class firemen, before taking the engine away from the round-house, is that of looking to the grates, and seeing that the ash-pan is clean. When grates get burned, in nine cases out of ten it happens through neglecting the ash-pan. Some varieties of bituminous coal have an inveterate tendency to burn the grates. Such coal usually contains an excess of sulphur, which has a strong affinity for iron, and at certain temperatures unites with the surface of the grates, forming a sulphuret of iron. Neglecting the ash-pan, and letting hot ashes accumulate, prepares the way for bad coal to act on the grates. Keeping the ash-pan clear of hot ashes is the best thing that can be done to save grates, since that prevents the iron from becoming hot enough to combine with sulphur.

TRANSMISSION OF HEAT THROUGH SCALE.

The Engineering Experiment Station of the University of Illinois has recently issued Bulletin No. 11, "The Effect of Scale on the Transmission of Heat Through Locomotive Boiler Tubes," by Edward C. Schmidt, M. E., and John H. Snodgrass, B. S. This bulletin describes a series of experiments begun in 1900 by the railway engineering department of the University of Illinois to determine the relation of the heat loss due to scale, to the scale thickness. The experiments comprise tests on single tubes, as well as tests of the entire locomotive boiler.

The results of all the tests, plotted with reference to scale thickness, show great divergence in the heat loss, which is ascribed to differences in scale structure. The bulletin is of interest to all who have to do with the operation of steam boilers in localities where pure feed water is not available. The conclusions derived from the tests are summarized as follows:

1. That for scale of thickness up to ⅛-inch, the heat loss may vary in individual cases from insignificant amounts, to as much as 10 to 12 per cent.

2. That the heat loss does increase with thickness in an undetermined ratio.
3. That mechanical structure of the scale is of as much, or more importance than thickness in producing this loss.
4. That chemical composition, except in so far as it affects the structure of the scale, has no direct influence on heat transmission.

CARE OF LOCOMOTIVE JACKETS.

There is nothing that adds more to the good appearance of a locomotive than a well kept jacket. The painting may be ever so nice, but the jacket, constituting as it does such a large portion of the engine, if it shows a lack of attention, presents about the same appearance as a man with new hat and shoes and a shabby suit of clothes.

Being unprotected by paint or varnish, constant care is necessary to prevent rusting. The treatment of a jacket on the road and in the shop is, or should be somewhat different. In the shop, preparatory to painting or varnishing the painted parts of an engine, the jacket should be thoroughly cleaned with benzine or gasoline, and the more stubborn parts, such as where the grease has become baked, should be removed with concentrated lye. After thorough cleaning it should be rubbed over with a piece of waste only slightly moistened in valve oil, this should be allowed to remain until the painting is completed, after which the jacket should be lightly wiped off with clean waste, leaving just a scum of oil to protect the metal, and to present a slight luster.

On the road, the jacket should never be without a slight film of oil, or in other words, it should be wiped with dry waste, which should contain just sufficient oil to clean and at the same time to leave a deposit to protect against moisture.

An excess of oil on a jacket is about as unsightly as the jacket that is never cleaned. This is not only unnecessary but is a waste of material.

The jacket that is once thoroughly cleaned can be kept clean with very little work.

LENGTH OF WATER GLASS.

From the lack of uniform practice in regard to length of water glasses on locomotives, it would seem that either this matter has not been considered of much importance or, that experience on the subject has been widely different. An investigation of the question, however, shows that it is worthy of careful consideration, and that the existing variation in practice is generally unwarranted. Present practice regarding the length of water glasses on different roads varies from eight to sixteen inches.

Primarily a water glass is an indicator for showing the depth of water carried over the crown sheet of the boiler. It was devised as an additional check on the gauge cocks for the protection of the crown sheet against low water, and consequent burning. While the determination of the lower level of water carried in the boiler was deemed important, it would seem that the amount of water carried above the safe point was considered of little consequence and a matter of choice with the engineer. Thus water glasses of all lengths are found in service, although little difference in the location of the lower fitting is observed.

The location and length of water glasses is important from the point of safety and economical performance of locomotives. For the protection of the crown sheet the water glass should be located at a standard height above this sheet, so that definite instructions can be issued to engineers, that will apply to all locomotives. The custom of not following a uniform practice in locating water glasses on different types of locomotives has resulted in burned crown sheets, which could not be properly charged to neglect of the engineer. Unless the height of the glass above the crown sheet is indicated, (which is seldom) the amount of water carried over the crown sheet is purely a matter of guess work to the engineer. He can be guided alone by past experience, and that is practically valueless when applied to conditions of which he knows nothing.

The length of the water glass is important, as it determines the maximum amount of water that will be carried in the boiler. The average engineer will carry the water as close to the "top nut" as possible. It is readily apparent that the water level maintained in the boiler bears a certain relation to locomotive performance. When too much water is carried the result is generally wet steam and priming, which destroys lubrication in valves and cylinders, and reduces the power of the engine. Under certain conditions, water is carried over into the cylinders in such quantities as to break out cylinder heads and bend pistons. The practice of carrying a high water level in a locomotive boiler is not productive of economical results.

Present practice tends toward the use of a shorter glass, averaging about eight inches in length. It is believed that this is the most practical length for a water glass on a modern locomotive boiler. As a change from the old practice to the new would entail considerable time and labor, the method followed by one road in shortening water glasses with little expense and delay, is worthy of note. The location of the top fitting was not changed, but a nipple of the proper length screwed on this fitting and over the glass, so that only the desired length of glass was visible. In this manner the shorter glass was secured at slight expense, and without taking the engine out of service. This practical method could be adopted by other roads to advantage.

WATER FOR USE IN BOILERS.

Water contains two classes of mineral salts, the incrusting and the alkali salts, the amount of which determine its fitness or unfitness for use in locomotive boilers. The sum of these would represent the total solids dissolved in the water, and would be the residue left on evaporation.

Total dissolved solids
1. Incrusting matter or total hardness.
    a. Temporary hardness or carbonates of lime and magnesium.
    b. Permanent hardness or sulphate of lime.
2. Alkali salts.
    a. Sodium sulphate.
    b. Sodium chloride.
    c. Sodium carbonate.

INCRUSTING SALTS.

The incrusting salts, or total hardness consist of the carbonates and sulphates of lime and magnesia, and may be divided into temporary hardness, and permanent hardness. Temporary hardness represents the carbonates of lime and magnesia. These salts, when the water is boiled at atmospheric pressure, are precipitated in the form of a soft scale or as a mud, which if allowed to accumulate, results in a dirty boiler and a tendency to foam. Permanent hardness is sulphate of lime.

When the water is boiled at pressures below sixty pounds this remains in solution and for this reason has been called "permanent" hardness. At pressures above this it separates as a hard scale on the flues, the result of which is continual trouble from leaky flues due to overheating of the metal.

ALKALI SALTS.

The difference between the total dissolved solids, and the total hardness would represent the "alkali" salts or the sulphates, chlorides, and carbonates of sodium. These salts remain in solution after the water has been boiled, their total amount increasing up to a certain concentration when foaming results. Waters high in alkali salts are, on account of the tendency to foam, unfit for boiler purposes.

TREATMENT.

There are, then, two evils that must be counteracted in a boiler water, the tendency to form scale, and the tendency to foam. The scale forming evil is remedied by the use of sodium carbonate, or as it is commonly called "soda ash." This is one of the alkali salts that exists in some waters, but it cannot exist in the same water with sulphate of lime as the two would react to form sodium sulphate and carbonate of lime. Now if a water containing permanent hardness, or sulphate of lime be treated with soda ash, this same reaction takes place within the boiler, the carbonate of lime being precipitated as a mud and, the sodium sulphate going into solution. The result is no scale on the flues, but the extra mud and increase in total dissolved solids aggravate the foaming trouble. A systematic and liberal use of the blow-off cock will keep down the foaming trouble in two ways; first, by removing the mud; second, by reducing the concentration of the water or total dissolved solids. It has been determined that when boiler waters contain over 200 parts per 100,000 total dissolved solids they are pretty liable to foam.

The usual practice has been to wash an engine out when it began to get dirty or show signs of foaming, but now we find that a sufficient use of the blow-off cock, especially the back water leg blow-off cock, makes it possible to avoid serious foaming troubles and to increase the engine mileage between washings very materially.

All laboratory analyses are expressed as so many parts per 100,000. This divided by 1.73 would show the same in grains per U. S. gallon.

SOFT COAL BURNING.

BY C. M. HIGGINSON.

The question of smokeless combustion of coal is attracting much attention at the present time, especially in western cities, where bituminous coal is the fuel most generally used. The agitation has reached such a pitch that ordinances have been passed by the common councils in several cities establishing a series of fines for the unnecessary emission of smoke within the city limits, from the chimneys of manufactories, steamboats or locomotives. The consequence has been that a large number of devices have been brought forward to public notice, having in view the combustion, or rather prevention, of smoke.

Economy in the use of fuel is another pressing need in these days of intense competition. In both manufacturing and railway work the coal bill forms a large percentage of the total expense, and any material reduction that can be made in the same reduces the cost of the article produced, or of transportation rendered. The desired economy may be arrived at through the following ways—by more care in firing; by more perfect coal burning devices; or by use of methods which will allow of burning with relatively good results a cheaper grade of fuel.

As a rule more attention has been paid by engineers to the question of the economical *use* of steam than to the efficiency and cheapness of its *production,* and in the latter item lies one of the largest economies remaining to the industrial world.

It is interesting to any one who has watched the question of practical coal burning for a number of years, to notice the rise and fall of different devices for promoting economy in this direction. Valuable improvements have been made from time to time, and, proving their efficiency, have been used for a while. By change of men directly interested, or on account of other circumstances, they are allowed to fall into disuse, with a corresponding loss in freedom from smoke, and a decreased economy of fuel. When the question is again agitated the same plan may be brought forward as an entirely new idea, and once more presented for public favor. In fact, of all of the devices now being introduced or experimented with, nearly every one is some new adaptation of an old invention. The ground has been so completely covered by investigation in the past that it is doubtful whether any new devices can have protection as far as general principles are concerned; but patents now issued are mainly granted upon the particular grouping or combination of parts used in each case.

That in stationary boiler plants a comparatively efficient combustion of bituminous coal can be effected with a very small output of smoke is well known to all who have given the matter close attention, and such performance can be reached with but little expense, and in many cases without the use of a single patented device. The simplicity of arriving at this end is often lost sight of through a variety of causes. Among them may be included the disposition on the part of those who have patented devices of their own to mystify the whole question, so as to enhance the selling value of their methods. There is also much want of definite knowledge of the subject among those who are large coal users, and often a lack of interest on the part of those engaged directly in firing or operating steam boilers.

The chemical questions involved in the composition of coal, and its economical combustion have been very fully treated by such writers as Williams, Clark and Prideaux, leaving but little ground uncovered, making it useless to fill out space with this class of subjects. Their investigations have shown, however, that in the combustion of bituminous coal a large proportion of the valuable heating material is in the hydrocarbons driven off when this coal is heated. How large the portion of this volatile matter is may be seen from the following analyses of well-known bituminous coals:

Table 24.

NAME OF COAL.	Fixed Carbon.	Volatile Gases.	Water.	Ash.	Sulphur.
Pittsburgh, Pa.	61.12	28.35	3.15	5.38	2.00
Erie, Pa.	59.13	28.62	3.85	6.10	2.30
Straitsville, O.	56.15	29.10	5.15	7.05	2.55
Hocking Valley, O.	53.48	28.65	6.05	8.45	3.37
Brazil, Ind. (best block)	58.79	25.45	5.46	7.47	2.83
Brazil, Ind. (average)	54.20	26.74	6.35	8.95	3.76
Fountain County, Ind.	50.28	29.40	6.15	10.15	4.02
Danville, Ill.	51.12	30.11	6.40	9.25	3.12
La Salle, Ill.	48.50	30.16	5.87	11.60	3.87
Wilmington, Ill.	49.36	28.87	7.12	11.25	3.40
Morris, Ill.	50.00	30.36	6.45	9.87	3.32
Streator, Ill.	49.70	29.11	6.87	11.20	3.12
Big Muddy, Ill.	57.80	28.64	4.85	5.96	3.75
Ladd, Ill.	47.69	37.79	7.00	5.30	2.22
Dunfermline, Ill.	42.49	40.44	6.65	8.90	1.52
Colchester, Ill.	56.80	30.80	5.40	5.00	2.00
Rushville, Ill.	52.90	31.60	6.00	6.50	3.00
Wyoming lignite	44.00	41.00	11.00	3.50	50

Without elaborating the question of the chemistry of coal combustion, which may be found in any of the works we have referred to, we may say that from the results of numerous analyses, we find that a good western soft coal from a dry mine, consists of 55 parts by weight of fixed carbon, 30 of volatile hydrocarbons and 15 of water, ash, sulphur and other waste matters. The combustible part of a ton of coal would therefore contain 1,100 lbs. of fixed carbon and 600 lbs. of various carbureted hydrogen gases. The latter will contain on an average 500 lbs. of carbon and 100 of hydrogen. The relative heating value of the amount of gas driven off when compared with that of the fixed carbon in the coal, is as 7 is to 8, when expressed in amounts of water that would be evaporated from 212 deg.

From the above figures we see that nearly one-half of the steaming value of this coal is contained in the volatile gases. Each pound of dry coal, constituted according to the above analysis, should evaporate, theoretically, about 14½ pounds of water from a temperature of 212 deg. In ordinary practice, however, the amount of water and ash contained in average western coals is larger than in our sample ton, so that the average steaming value possible for western soft coals can be considered as 13 lbs.

Sulphur is a combustible element, but the value of the heat derived from it is more than counterbalanced by the damage done to the iron of the furnace. The gases forming the water contained in the coal are very combustible, being oxygen and hydrogen, but the heat given out by their combustion only balances that absorbed in decomposing the water to form them, so no real benefit is gained. This fact is lost sight of by many inventors, who lay great stress upon the decomposition of steam forced into the firebox over the burning coal as an aid to combustion.

In locomotives the use of the same principles that apply to stationary boilers will do away with much of the trouble which inventors are attempting to meet by means of spark arresters of all descriptions. As regards the question both of smoke and spark prevention in locomotives, it is much cheaper in the end to hinder the sparks from leaving the firebox than to endeavor to collect, or arrest them after they have once passed through the flues. The examination of the sparks that will collect upon front cars of freight trains, on station platforms, or in the extended ends of locomotive boilers will convince any one, we think, that much valuable heating material is wasted in this manner.

With stationary boilers the question of loss through coal thrown from the chimney does not arise, but for all classes of furnaces it is now a recognized fact that smoke once formed can not be done away with. and any improvements must be in the line of preventing its formation.

No matter how perfect the device is, a large portion of the ultimate success depends upon the firing, and without care in this direction anything short of automatic stoking may be rendered useless.

In order to obtain economical and smokeless combustion of soft coal in any form of boiler it is important that all the following conditions shall be met:

1. A good draught.
2. Open grate bars.
3. An air supply over the fire.
4. An intimate admixture of air with the burning coal gases.
5. Distance in which to complete the combustion of the mixed air and gases.
6. Heating surface sufficient to conduct the heat developed to the water in the boiler.

The above conditions will probably be accepted as axioms by the majority of steam users and engineers, but in practice it is a rare thing to find a boiler or furnace either for stationary, or locomotive use that presents all of the requisites for good work. It may be profitable therefore, to look more in detail into the points involved in good practice, The matter of a good draught is most important when natural draught alone is depended upon, as in the case of stationary boilers. To get good results from any class of coal a draught is necessary which would be at least equal to ½-inch water pressure in all conditions of the weather. Low chimneys—chimneys of too small area—too small connections between the boilers and chimneys—sharp corners in such connections—leaky brick work around the boiler, and the interference of the currents from different boilers, are all responsible for much waste of money, and great smoke production in many steam plants. These are all matters which, as a rule, can be simply and cheaply remedied.

One of the oldest and simplest devices for improving the draught temporarily, is the steam jet invented many years ago by D. K. Clark. This method has been the basis of a large number of plans for better combustion. A series of jets can be cheaply arranged at the back end of the furnace, so directed that the blast from them will just clear the bridge wall, and will aid a poor natural draught. Each small steam jet is generally surrounded by an annular opening which allows air to be drawn in from the outside to help burn the gases, though this is not always done. It must be remembered, however, that these jets use a certain proportion of the steam developed by the boiler, and they need not be employed when there is a good natural draught. Various modifications of exhaust fans in the stack have also been used to this end.

The result of general experience shows that in both locomotive and stationary boiler practice, there should be openings through the grates equal to fifty per cent of the total grate surface, yet in many cases not even twenty to twenty-five per cent is used, and surprise is expressed that the plant does not do good work. There should be also a free access of air to the grates, but we sometimes find stationary plants run with the ash pit doors closed, or locomotives with openings into ash pans much smaller than area of openings through grates.

Careful experiments have shown that the bulk of the air which is necessary to burn the gases driven from the coal must be let into the firebox above the line of the fire. It is claimed by some that this can best be done by running with such a light fire that a surplus of air can pass between burning coals sufficient to unite with the gases above. While this might be done with theoretically perfect firing, we find in practice that in the effort to have the fire thin enough to admit of the passage of air through it, holes are left which allow such quantities to pass through that the steaming qualities of the boiler are interfered with. When the firing is too heavy, aside from the loss by gases driven unconsumed from the top of the coal, there is an additional loss from the fact that the carbonic acid formed in the lower part of the bed of coals in rising through the glowing coals, takes up a further amount of carbon, forming carbonic oxide, the additional carbon so taken up being wasted. The supply of air let in above the fire aids in burning this gas also. Carbonic oxide gas burns at a lower temperature than carbon, and with a light blue flame forming carbonic acid. It is this gas burning which gives the light blue flame so often seen in hard coal stoves and furnaces.

In order to obtain the benefits of running with a thin fire, it has often been the practice with both locomotive and stationary boilers, to use too large a grate surface for the size of the boiler plant. The result is that more coal has to be burned at times than is economical, merely to keep the grate covered in order to keep cold air from rushing through in quantity. When doing hard work the quantity of heating material produced may be too much for the boilers to take care of as designed, and the consequence is a loss of heat through the stack. The writer has seen good results, both in locomotive and stationary boilers by reducing the grate areas. In locomotives an area of 2.3 to 2.5 square feet of grate surface to the cubic foot of cylinder volume is a good proportion for road engines, and 2 feet for switch engines. In stationary practice a grate five feet long, and the width of the boiler will give good results with all grades of soft coal.

We have already stated that experience shows that the air needed to burn the gases arising from bituminous coal gives the best results when admitted above the line of fire. Several other conditions are also necessary to insure perfect success. One is that there shall be no chance of large quantities of cold air passing through the tubes, and interfering with the steaming qualities of the boiler. The smaller these air jets with ordinary boiler settings are, the more intimate will be the mixture with the burning gases, and the more perfect the combustion. It is also necessary that the air passages be near the top line of the burning coal, so that the air entering can mingle with the gases as soon as possible after they are evolved. In case larger openings are used, it is necessary to provide some method of producing an intimate mixture soon enough to allow a flame way for the burning combination before reaching the flues. It is also well to keep the line of the incoming currents of air away from the metal of the boiler proper, until the mixture of gases and air has been effected, and combustion fairly under way.

Another important factor is the area of such air passages. It has been found by trial that with long flaming coals, and average firing, the best results have been obtained when such air passages averaged one-thirty-fifth of the grate, when natural draught was used, and one-fiftieth when a blast was used, as in the case of a locomotive. The area of these air passages should also vary according to the proportion of volatile matter contained in the coal, more being needed with a light coal than with one containing a large amount of fixed carbon. The proportions we have given above under the different conditions of draft, admit the necessary volume of air in addition to what passes through the burning coal, to effect the perfect combustion of the gases. In the case of anthracite coal not more than one-quarter of the above will be necessary, as only the carbonic oxide gas has to be provided for.

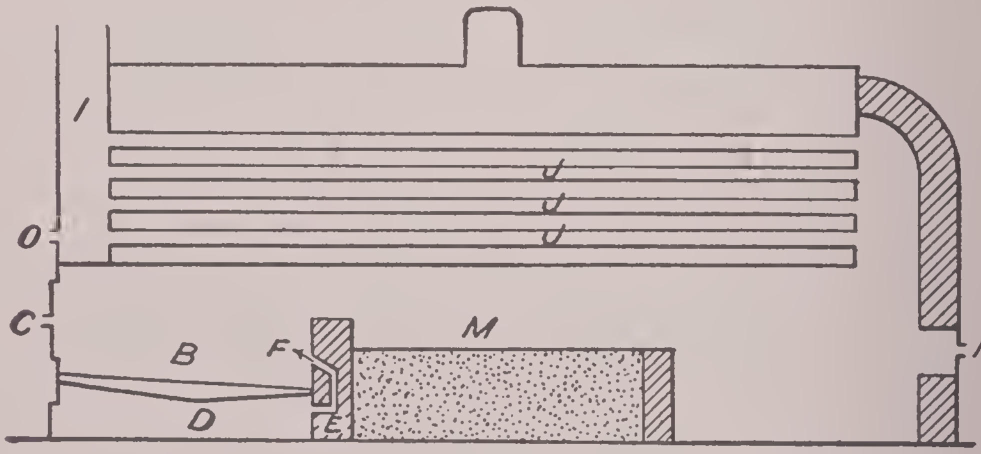


Fig. 147.

When we come to the different methods of admitting air above the fire, we find that it may be done in a variety of ways. A large number of different devices are offered, but they are mainly adaptations of the following methods: In Fig. 147 is shown a common form of stationary boiler with fire grate *B*, door *C*, ashpit *D*, bridge wall *E*, flame bed *M*, flues *JJ*, and smoke flue *I*. In this figure we have shown the air entering through flues built in the bridge wall, and connecting from the ashpit to the furnace above the line of fire. The openings *F* can be molded in fire brick if desired, and can thus be made more numerous and smaller in size. The method of admitting air is an adaptation of what was originally known as the "Split Bridge." It may be well to state here that a "split bridge," through which the air passes in front of and over the bridge wall, gives better results than when the mixture of atmospheric air and gases is effected back of the bridge wall. There are many other methods which can be easily used, of admitting air at, or near the bridge wall. A sight hole in the cleaning door *N* will enable the performance of the fire to be closely watched. If we have a good proportion of air supply, and fairly careful firing the working of the fire can also

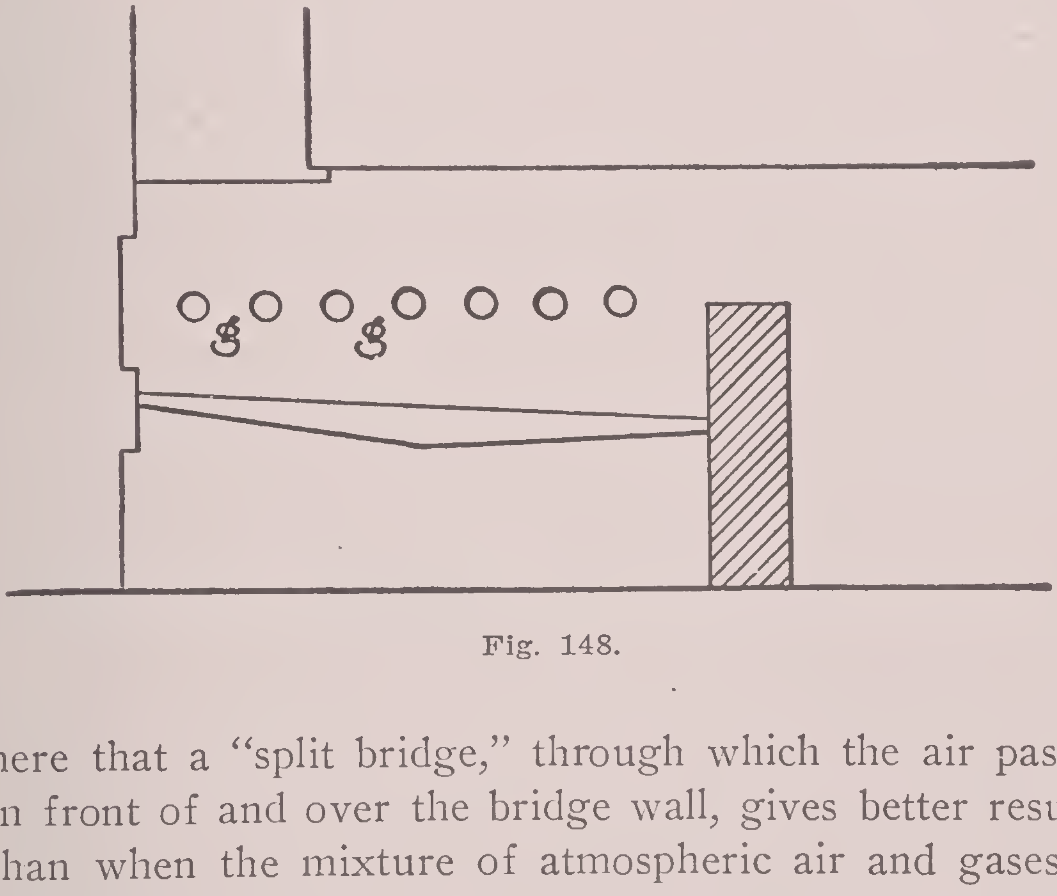


Fig. 148.

be watched through a small hole at *O* opposite one of the flues. The line of sight through the center of the flue will allow us to note the condition of the fire by the reflection on the brick work at the back end.

The same watch may be kept of the workings of the other methods we show. In Fig. 148 we have the same construction of boiler and firebox, only the latter being shown. Here the air is admitted through one or more rows of holes, *gg,* in the side of the firebox, some 3 inches or so above the line of coal. In another method, shown in Fig. 149, the air is admitted through dampers in the furnace door and is distributed through small holes in the outside lining of the same at *H*. This method has the advantage of being easily regulated if desired, but in ordinary practice there is not the necessary amount of air space allowed in the outside dampers.

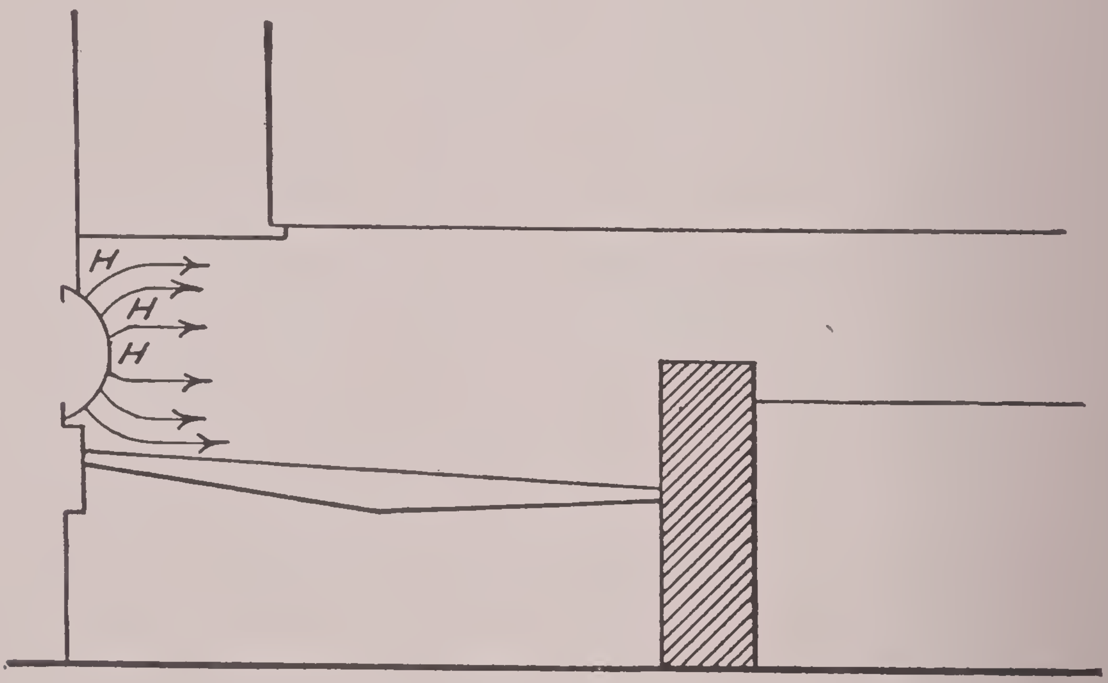


Fig. 149.

The same result has been reached by running the fire as shown in Fig. 150. Here the ends of the grates near the fire door are left uncovered for an inch or so and the air from the ashpit enters, and passes over the fire, mixing with the gases. Various modifications have been made of the foregoing methods of construction with fairly good results.

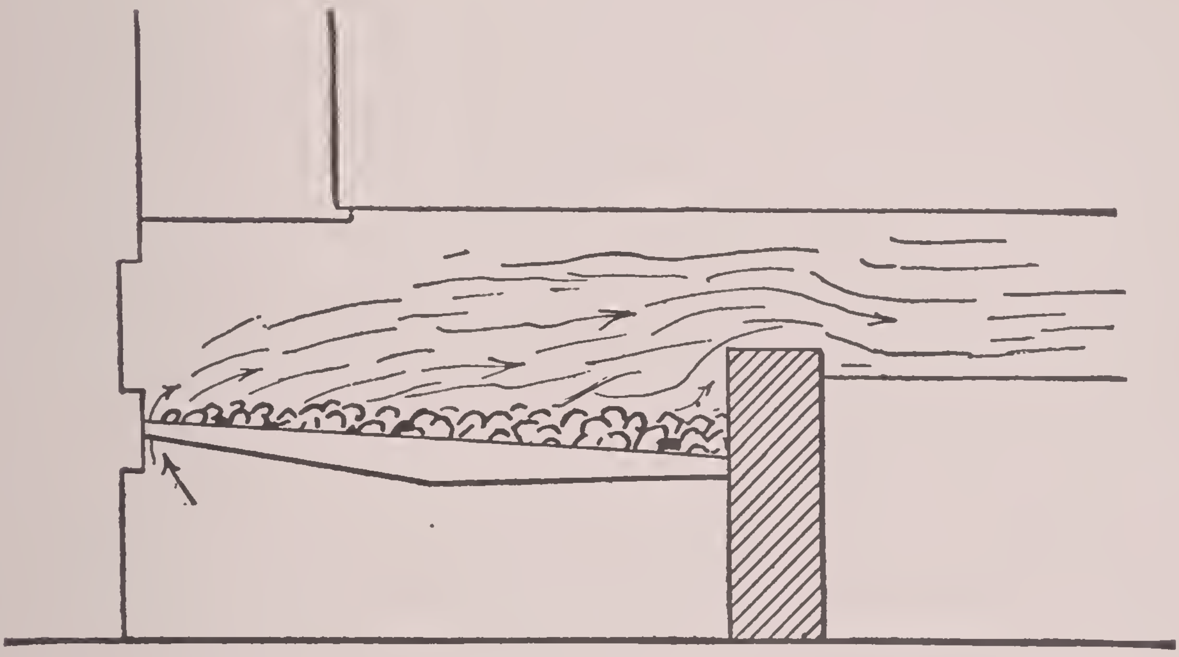
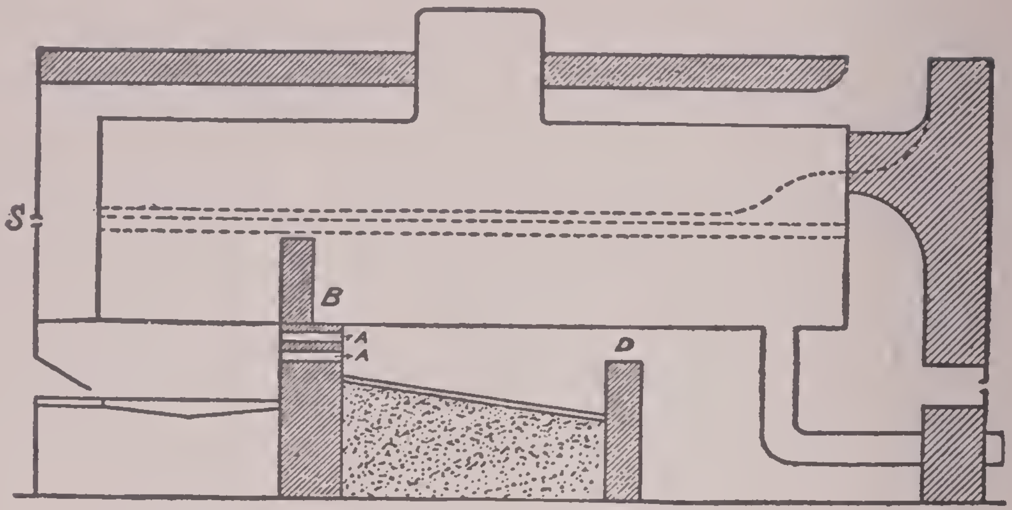


Fig. 150.

It very often happens, however, that the gases and air do not get well mingled at the bridge wall, but go over it in separate layers without forming perfect combustion, and this trouble has been a stumbling block to inventors who had with this exception successfully working devices.

To obviate this difficulty the form of setting shown in Figs. 151 and 152 may be used with success. In this construction the currents of atmospheric air and coal gases are mingled by passing through the flues at *AA* in the bridge wall, and burn with an intense flame. The upper part of the bridge wall is closed solid at the sides



.Fig 151.

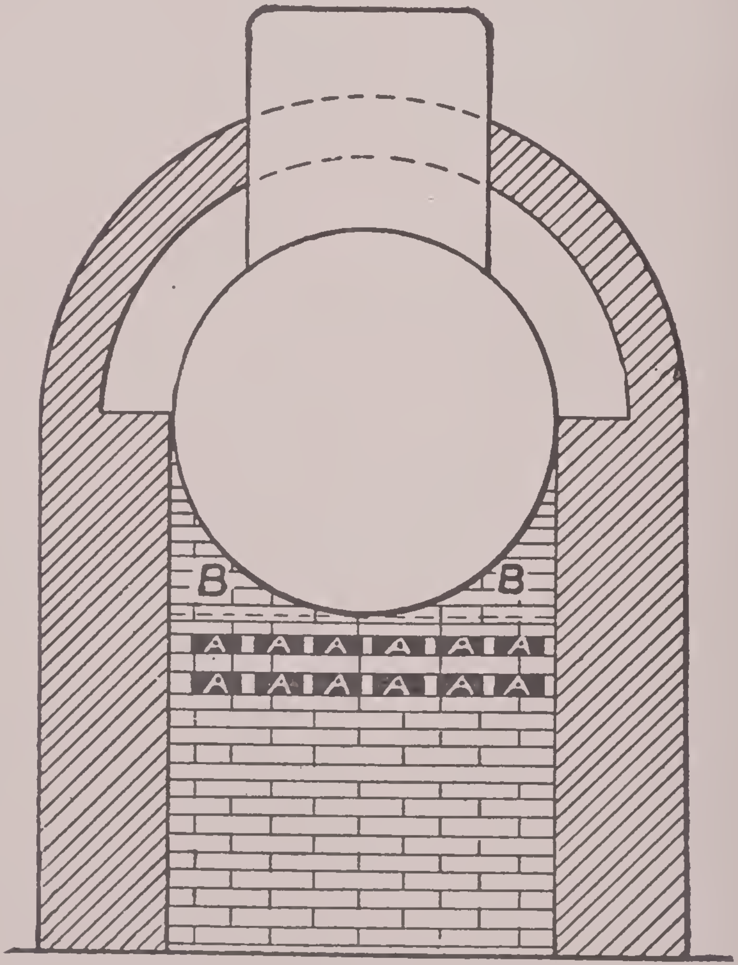


Fig. 152.

of the boiler to prevent the passage of air currents, except through the brick flues. The area of the openings in the bridge wall depends somewhat upon the quality of coal used, and the amount of draught, an ordinary proportion being 15 to 20 per cent of the grate surface. Instead of the brick checker work, small arches may be used, the aim being to make the burning gases go *through,* instead of *over* the bridge wall.

The volumes of air that can be economically used at the door opening with this style of setting will surprise many engineers. For this abundant admission, however, it is necessary that proper methods of admixture with the coal gases be supplied, and it is mainly in presenting a simple means for such admixture that we consider we have materially advanced practice in the line of efficient combustion beyond the results reached by earlier experiments. The form of perforated bridge wall here shown, as well as others of the same general character, in addition to the work of mixing the gases and air, have the additional advantage of keeping the burning gases away from the comparatively cool boiler until their combustion is effected. After this point, the sooner the heat contained in the currents of heated matter is absorbed by the water in the boiler, the better will be the total effect obtained. The form of the flame bed back of the bridge wall can be varied to suit long or short flaming coals. The small sight hole at *S,* placed opposite the center of one of the tubes will allow the light of the flame at the back end to be readily watched, and the air supply can be regulated by this means without opening the furnace door.

The claim is sometimes made that air entering the fire should be first heated to produce the best results. Experiment, however, does not seem to show that this is necessary, except for some special purposes. In blast furnaces the entering air has to pass through the melted product to some extent, and an advantage is gained by having it heated, but in ordinary boilers this does not seem necessary, as the same heat expended in one place to heat the air entering the furnace is lost in another from the purpose of evaporating water to form steam.

The wall shown at *D* has the effect of making the heated gases impinge against the boiler after the combustion is finished, thus parting with heat to the water in the boiler more readily. A curve in the flame bed up to this point will have the same result.

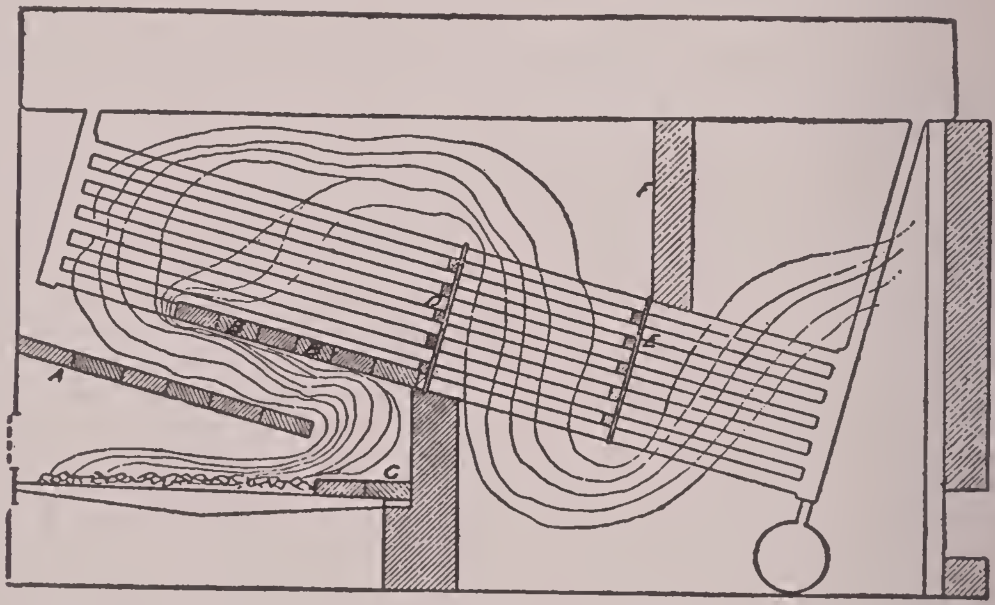


Fig. 153.

The same principles should be applied to the various forms of water tube boilers, which are often very bad smokers, as also to the various forms of automatic stokers, and down draft furnaces.

One such adaptation is shown in Fig. 153. Here *A* is a fire brick arch, supported in any desirable way, *C* is a short flame bed next to the dividing wall, and *BB* is a fire brick roof which can be put in, in various ways, and which prevents the flames from passing directly among the water tubes. This combination provided for an air supply at the door, its admixture with the burning gases, and a sufficient flame way to allow of complete combustion. Results with this and similar settings for the various water tube boilers have been very gratifying, both as regards high evaporation, and freedom from smoke. With a form of water tube boiler where a roof of fire brick is placed between the tubes in the lower row, a bridge wall similar to that shown in Fig. 151 has been successfully used.

It is often found that even with a long flame way and tube run, the gases still pass into the chimney at too high a temperature. To obviate this the return flue over the top of the boiler, as shown in Fig. 151, has been used with good success. In many cases the heat of the gases leaving the tubes from the ordinary type of boiler has been found to be from 650 to 750 degrees.

It is claimed sometimes that the admission of any appreciable amount of air over the fire by methods such as we have shown with ordinary furnaces will have the effect of cooling down the flues. That such is not likely to be the case when the air enters the furnace in small jets can be shown by actual experiment with a stationary boiler, the results of which are illustrated in Fig. 154. Here *BB* are the inner and outer firebox shells with a water space, *A,* between, and *C* is the opening, admitting air from the outside. This tube, *C,* admitting air into the furnace was two inches in diameter, which is much larger than would be generally used. Upon looking through this opening it could be seen that the current of air entering the furnace assumed the conical form, shown at *D,* as it met and united with the gases of the coal rising at *EE,* and the extreme apex of the cone was not more than 6 or 8 in. from the inside wall of the firebox under natural draught, showing that in this case at least no body of cold air reached the flues. With a smaller orifice, of course, the distance traveled by the current of air before being absorbed is shorter. When the openings are larger there is more necessity of other means of accomplishing an intimate mixture of the air and burning gases.

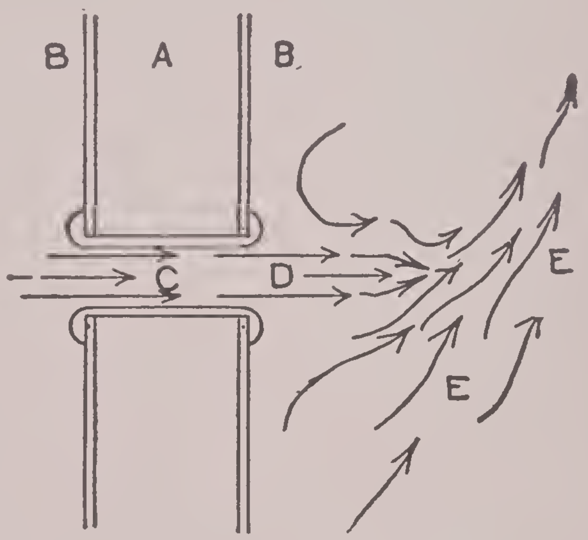


Fig. 154.

When the necessary conditions heretofore referred to are filled, an efficiency should be reached in dry steam produced equal to seventy-five per cent. of the theoretical value by analysis of the coal in question. When lower figures are shown by a careful test of any steam plant it may be taken for granted that some of the needed conditions have not been met, and steps should be taken to find out and remedy the trouble.

The same principles apply to locomotive construction equally with stationary engine boilers. The conditions are somewhat different, however, owing to the shorter flame way, and the harder draught, which shortens materially the time in which combustion can be completed. It is a well known fact that no combustion can go on within the small tubes of the locomotive boiler. It is often the custom, therefore, to increase the original flame way by means of a deflector made of fire brick, or by what is known as a "water table," being a metal deflector with a water circulation inside to keep it from burning out. The former appliance seems to be the most successful, owing to the higher heat reached by the brick (which aids in the combustion of the mixed gases and air), as well as on account of cheapness of construction and repairs. One of the most perfect combinations that the writer has seen of this construction is that shown in Fig. 155. This cut shows a portion of an ordinary locomotive boiler with dome *K,* firebox *A,* firedoor *B,* grate *C,* flue sheet *G,* and tubes *HH.* Here the firebrick slabs *E,* extending across the box, are held up by water tubes *D,* as shown in the cut. These tubes are connected with the water spaces of the firebox in such manner that a circulation of water takes place through them, preventing burning. The arch as thus put in prevents the direct passage of cold air to the tube sheet. In some cases when the water is bad the arch may be supported by studs instead of water tubes.

Above the line of fire, and extending completely around the box, are three rows of hollow stay-bolts *MM,* each having an opening of ⅝ in., the total area of opening amounting to 1-50 of the grate surface. The results from such a construction, well fired, are that an intensely bright fire is produced, while but little smoke is evolved from the stack. When the attempt was first made by American mechanics to admit air over the fire in locomotives at other points than at the door, reports were not infrequently made that the employment of hollow stay-bolts showed no advantage from their use. This result invariably followed from not using enough of them or, from not using those of a large-enough size to let in the necessary amount of air. The following table will show the relative areas of different sizes of stay-bolts:

Diameter of aperture.	Area square inches.
¼ inch	.049
⅜ inch	.110
½ inch	.196
⅝ inch	.305
¾ inch	.442

It will be seen, therefore, that the difference of area between 100 hollow bolts of varying diameters entering a firebox is very wide. Compare the area of those of ¼ and ⅝ in. diameter, and in the former case it amounts to 4.9 sq. in. and in the latter to 30.5 in., and the relative amounts of air let into the box vary accordingly. The same type of firebox (Fig. 155) may be used to advantage when boilers of the locomotive pattern are used for stationary purposes, as more time is given and more room afforded for the perfect combustion of the volatile gases. The conditions being more unfavorable, the matter of firing can make a greater difference in a locomotive, than in a stationary boiler. Engines experimented with, having exactly the same dimensions and running on the same division with similar trains have, by difference in care used, shown the extreme limits we have indicated of 4 to 8 lbs. The matter of determining by experiment, the amount of water evaporated by locomotives is comparatively simple, requiring no special apparatus, and we are glad to see that more is being done in this line than in the past. There are many roads yet, whose managers would be surprised at the low performance shown by their motive power. With long shallow fireboxes, when a brick arch cannot be readily put in, the grates may be

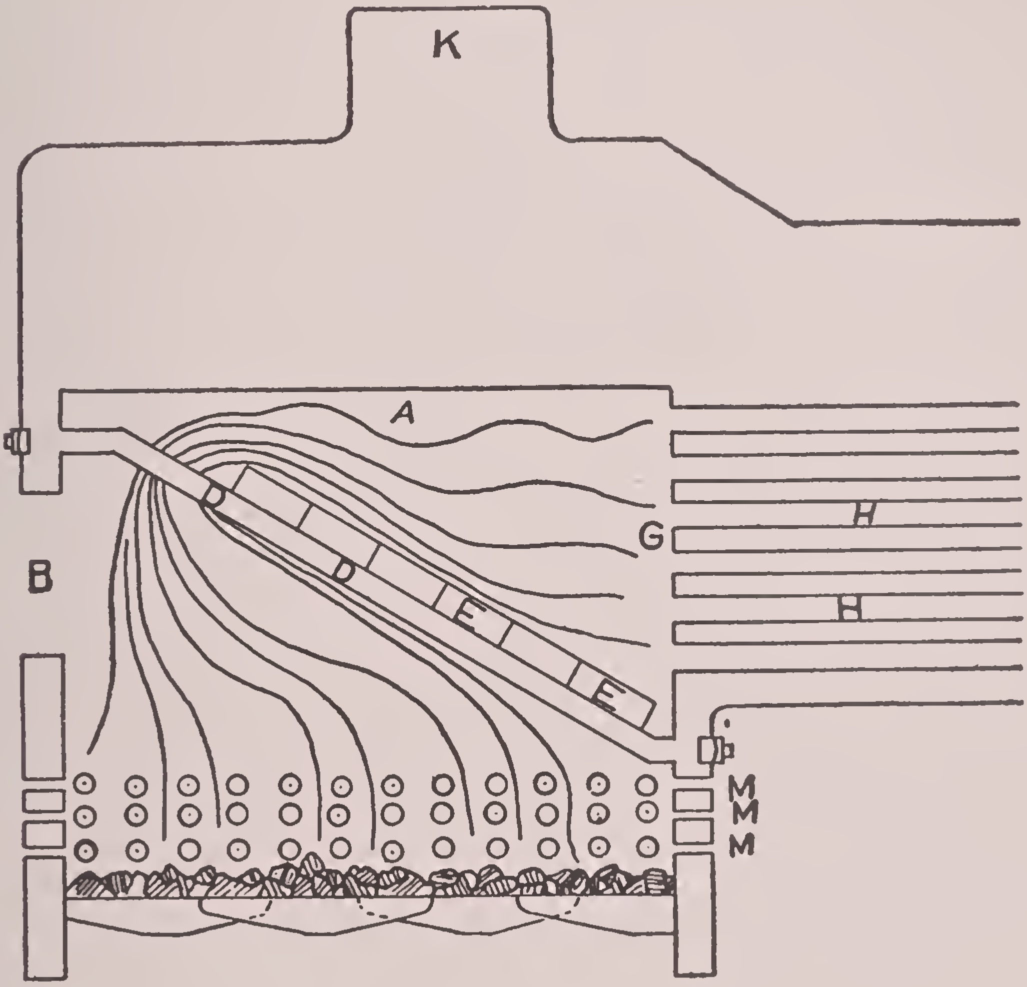


Fig. 155.

bricked up at the front end to reduce their area to proportions already referred to, and a wall of brick built on this floor will form a good combustion chamber and improve the performance of the boiler.

The most efficient combination of various smoke-preventing devices for locomotives that have been tried here and abroad may result in a construction somewhat like that shown in Fig. 156. Here we have the same arrangement of firebox as in Fig. 155, but from the flue sheet forward there is a radical change. From the firebox the burning gases pass through a series of tubes, *HH,* not over 2 ft. in length, but having an inside diameter larger than the ordinary 2-inch tubes. Next comes a combustion chamber at *J,* 30 in. or so in length. Finally, starting at the tube sheet *F,* we come to a series of the ordinary pattern of smaller tubes running to the front flue sheet at *P,* in the smoke arch, *L.* The advantages claimed for this construction are several, and may be described as follows: The ordinary 2-in. tubes are not large enough to allow of the combustion of the gases driven from the coal, to be carried on within them for more than a foot or so, and the length of flame way which is often too short is thus limited. This would not be the case when using larger tubes, and we would have a current of ignited gases passing through them into the combustion chamber. It is a well proven fact that the firebox surface of a boiler, and the first few inches of the flues are the

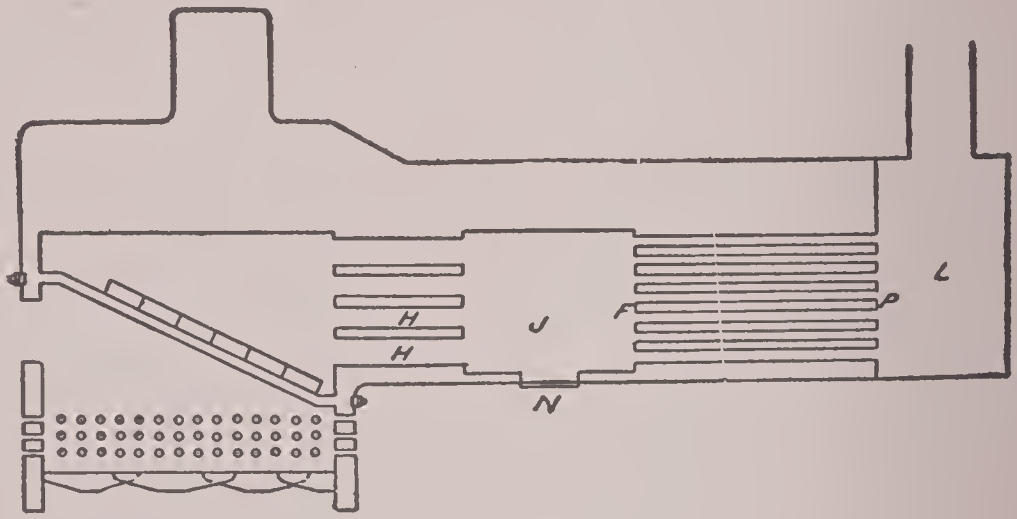


Fig. 156.

most valuable for steaming purposes, there being much less result from the last few feet of a long tube. The reason seems to be, that a current of heated gas striking the mouth of a tube rebounds, as it were, from side to side. After a while the motion, under the influence of the draught, becomes more direct, and less heat is given out through the metal to the surrounding water. Fig. 157 will represent the probable action of the gas currents in a tube, with the pitch of the probable course taken intensified. Here *A* is the tube and *BB* the flue sheet; *CC* shows the currents entering, and *E* those leaving the tube. That the gases pass through the tubes without parting with as much of their heat as is necessary for the economical use of fuel is well known. Experiments made with a pyrometer show that, in a locomotive with natural draught, and at rest, the gases issue from the front end of the tubes at a temperature of from 600 to 700 degrees, and that, when working, the temperature rises to 800 and 900 degrees, and even higher. These temperatures show a loss in evaporating power for every degree of heat in these gases above 350 degrees, which is the temperature of water under a steam pressure of 125 lbs. The effect of the construction we have shown will be to make the action of the currents more irregular, and a greater portion of the heat will consequently be absorbed by the

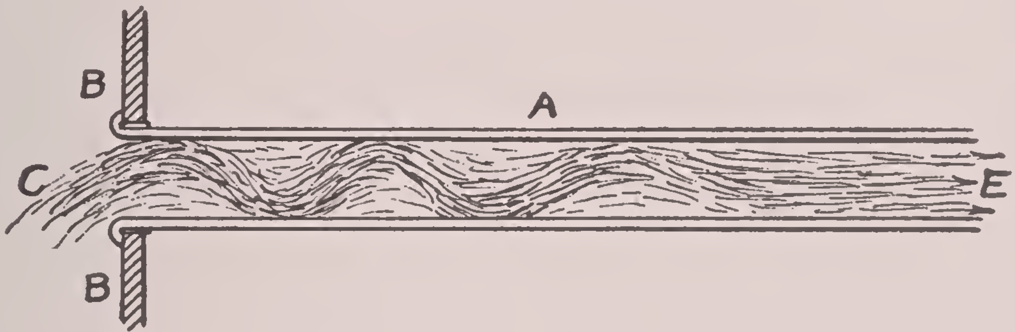


Fig. 157.

water through the metal. The use of some form of corrugated flue increases the absorption of heat by the water in the boiler, and thus reduces the loss through the stack. Moreover, the flame way being much larger, there will be a better chance for complete combustion, especially after the air entering through the hollow stays has been thoroughly mixed with the burning gases by striking the brick arch deflector. A simple form of feed water heater will aid in absorbing some of the heat passing through the smoke arch.

In designing a boiler similar to Fig. 156 care should be taken to have the steam and water space ample, otherwise the introduction of the combustion chamber while improving the combustion and giving a better quality of heating surface may, by taking up too much room injure the storage capacity of the boiler for water and steam.

An example of the effects of a close admixture of air with coal gases may be shown in the methods of burning pulverized fuel. Dust coal when blown into the firebox bursts into flame almost explosively without smoke, each particle of fuel being surrounded by air for its combustion A familiar example of the effect of change in direction of currents of heated air confined in channels may be noticed in an ordinary wood burning stove having two elbows in the pipe, one near the stove and one near the ceiling of the room where the pipe enters the chimney. A hot fire of shavings built in the stove will have the effect of making the pipe red hot at both elbows, while between these points the temperature will be much lower. Here the effect of the change in direction of the confined gases, by giving out heat to surrounding bodies is clearly shown.

Another advantage which is claimed for this construction is, that a less powerful draught will be necessary, thus obviating the need of expensive and complicated spark arresters in the stack. The use of a simple straight stack will allow of large exhaust nozzles being used, which in turn will do away with a portion of the back pressure in the cylinders, thus aiding the economy of the device. The system of hollow stays, shown in both Figs. 155 and 156, plays a useful part by preventing an excessive throwing of fire from the stack when the engine slips. When this occurs, the extra current of air is drawn into the box through these stays, and not through the bed of burning coals, thus avoiding the bad "tearing" of the fire usually met with.

This combustion chamber, *J*, may be fastened into the boiler shell by stay-bolts, as in the ordinary firebox, or may have crown bars on top, or a stay-bolt connection with the top of the boiler shell. It could also be used in radial stay, or Bellepaire boilers. It should be of such size that it could be entered through a manhole at *N* for the purpose of repairs. This form of combustion chamber, it is believed, offers less mechanical objections than a pattern which consists of a long prolongation of the firebox into the boiler shell, with which there is sometimes trouble on account of the extended crown sheet, and in addition affords much more heating surface.

This general plan of construction has been used experimentally with, it is claimed, good results, by a number of investigators. Compound engines upon the London & North Western, as exemplified by the "Queen Empress" at the Columbian Exposition, furnish a marked example. We would make the following criticism of this engine if desired for use on Western roads. A large tube between the firebox and the combustion chamber would allow a longer flame way, resulting in more complete combustion, and better performance in fuel. The arch in some form should come higher up in the firebox than was the case with the "Queen Empress," which would again give a longer flame way and protect the tube ends when the fire door is opened.

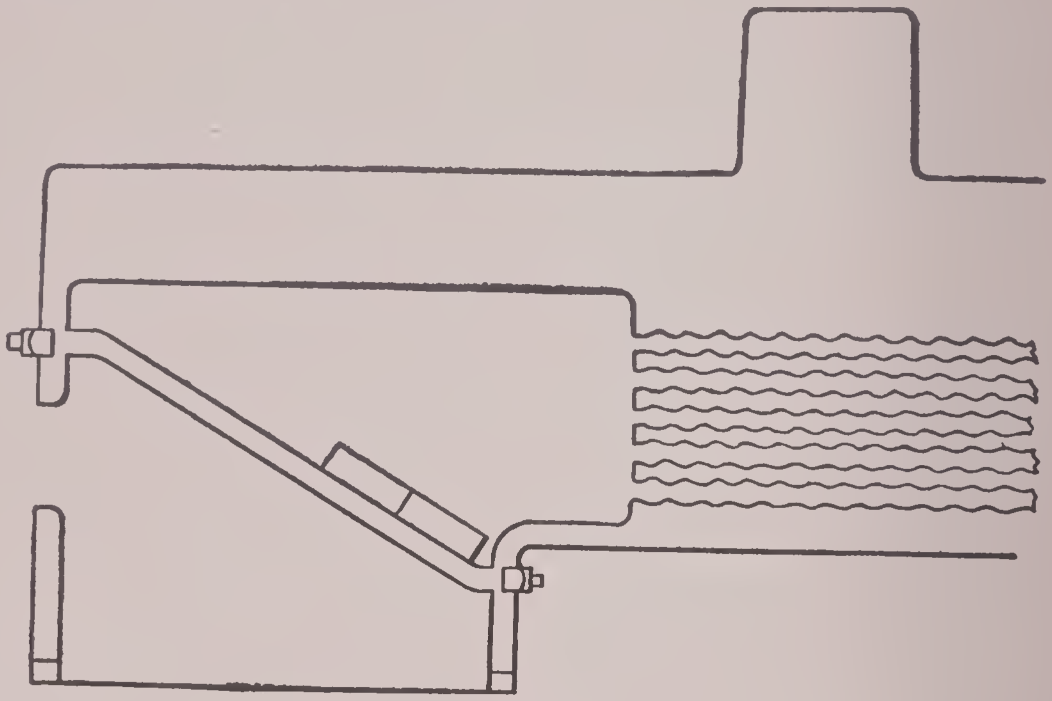


Fig. 158.

A combustion chamber formed of a moderate prolongation of the firebox into the boiler shell, as shown in Fig. 158, has given very good results, and would undoubtedly be preferred by many to the separate combustion chamber. Many of the criticisms upon the use of combustion chambers in the past have been warranted, from the fact that the conditions for complete combustion have not been provided. Unless this is done there is no particular advantage in the additional flame way. Corrugated tubes as shown in the drawing, would increase the evaporative efficiency if used. The corrugations may be of easy curve, so that no accumulation of ash will take place in the tube, and the scale can be cleaned from the outside surfaces.

Modifications of the ribbed tubes used abroad will also give good results. A combustion chamber can in many cases be formed by bricking up a portion of the grate surface, in which case an adequate air supply can be obtained through suitable openings in the brick work.

The question of heating surface belongs more to the economical, than to the smoke preventing side of the question we are discussing. The following proportions of heating surface to grate area seem to have proved their value for western coals: For stationary boilers with draught from ½ to ¾ inches of water 50 to 55 feet of heating surface in tubes and boiler shell to the square foot of grate area. For a draught over ¾ inches we should have over 55 feet of heating surface to the square foot of heating area, while with locomotives the nearer we can reach a ratio of 80 to 1, the better the results that will be obtained. Many master mechanics have in the past made the mistake of having too large grates, which are hard to keep covered, and often develop more hot gases than the firebox and tube surface can absorb the heat from.

As with many soft coals a flame way nearly twenty feet is needed with heavy firing, and natural draught it can be seen that many existing boilers of the ordinary tubular type are too short to give the best results in economical combustion. A good proportion may be considered as 16 feet in length for boilers less than 54 inches in diameter—18 feet in length for boilers over 60 inches in diameter. The increase in length has of course the effect of increasing the heating surface, which is often too small. This trouble does not as a rule exist in the ordinary types of water tube boilers, where there is usually ample heating surface, but an insufficient flame way.

The class of boilers in which the most difficulty is experienced in promoting successful combustion, especially without emission of smoke, is the upright variety, such as is often used in small boats, and for manufacturing purposes. Here the flame way is so short that it is hard to produce a complete combustion before the burning gases are extinguished by entering the tubes, which in this class of boilers are always small. In such construction it is probable that the most complete results can be reached by the use of some adaptation of currents of air forced into the firebox by means of a steam jet, which has the effect of throwing the air to the very center of the coal bed, and producing more complete combustion in a shorter time, and with less length of flame. The steam jets, it must be understood, play no part in promoting combustion, except by being the mechanical agents for supplying the necessary quantity of air. In some cases good results have been reached with boilers of this class by a judicious arrangement of firebrick deflectors, and an added air supply.

Successful boilers for use in small steamboats may be built after the pattern of locomotive boiler shown in Fig. 156, while a modification of the usual marine type of boiler for large boats may be used, embodying the method of furnace construction shown in Fig. 151. The principles commented upon in these pages may also be successfully applied to the use of coal in house furnaces, stoves, and open grates with a marked economy of fuel.

As was stated in the commencement of these notes, the writer makes but little claim to original discovery in the matter of coal burning, but merely notes down results of methods and experiment covering a long period. As the different constructions noted have nearly all been successfully used, with economical results, the fact seems proved that considerable progress has been made towards efficient, economical, and smokeless combustion. There is no reason why the results arrived at by the adoption of well known devices, and principles, should not be duplicated anywhere under the same conditions, and the efficiency of the average steam-making plant for all purposes much improved.

THE GRADE OF FUEL TO USE IN LOCOMOTIVES.

One of the most important considerations in connection with the question of fuel economy is the selection of the proper grade of fuel. It must be fairly uniform in quality, or it will be impossible to use it economically. A front end arrangement, or grates suitable for one grade of coal, may be entirely unsuited for another, and the fireman cannot obtain good results where the grade of fuel is constantly changing.

Ordinarily it is not possible for the railroads to secure a run of mine coal. A 5 or 6 in. screen is used at most of the mines, and the larger coal is used for commercial purposes. The mines can usually insist on this, because the railroads can secure a long haul on the superior grade of coal. On the other hand the mine operators are anxious to make contracts with the railroad company to insure keeping the mines in operation during the summer months, when the commercial requirements are light. During the dull period the work is usually confined largely to the making of headings, and the opening of new rooms, and in getting things in shape to be pushed when the heavy demand comes. The railroads thus often secure a better grade of coal during the summer months than during the remaining part of the year. While there are instances where it might be in the interests of economical locomotive performance to confine the buying of coal to certain mines, yet the development of the district, and the building up of traffic along a certain part of the line might make it advisable to secure coal from other mines. While the railroads usually do not get the best grade of coal, they pay less for it. Roughly, the mine operators get from 10 to 40 per cent. more for commercial coal than for railroad coal.

While the above considerations are important they should not be allowed to overshadow the desirability and importance of buying the coal on a heat value basis. There is a great difference in the heat value of different coals, and while the subject has been given very little attention by most of the railroads, it is of prime importance. It is of interest to note that as a result of coal tests made at St. Louis by the United States Geological Survey, the Government is purchasing coal for about forty departmental buildings at Washington, and for public buildings throughout the country on a simple specification, the prime elements in which fix the amount of ash and moisture in anthracite at seven per cent. Premiums are paid for any decrease in the ash content up to two per cent. above the standard, and corresponding penalties are fixed for any increase in ash above the standard. Better and more complete specifications, but more difficult for the dealer to fulfill, have been fixed by a few of the largest manufacturing and power concerns of the country, in which penalty and premium are paid not only on account of ash and moisture content, but also on the basis of the British thermal units as specified in the contract.

WEIGHING COAL ISSUED TO LOCOMOTIVES.

(From the *American Engineer and Railroad Journal,* April, 1908.)

There are several methods by which the coal delivered to the locomotive tenders may be measured with more or less accuracy. Unfortunately most roads have several types of coaling stations, built from time to time, some of which measure or weigh the coal issued, while others do not.

Unquestionably the greatest gains which may be made in fuel economy are in its use on the locomotive. The enginemen, however, cannot be watched closely and spurred on to better efforts, unless a careful check is kept on the coal consumption, and on those things which effect it. This cannot be done unless some means is provided for measuring the coal issued to each engine, with a fair degree of accuracy.

Under proper supervision there seems to be little question but what the average fireman could save one scoopful of coal in every ten. The simplest method of measuring the coal is the use of the jib crane and bucket system, or where "buggies" are used. The average weight of coal which one of these buckets or buggies will hold can easily be determined, and care can be taken to see that they are loaded uniformly each time. As a large percentage of existing coaling stations are of the above types, the practice on the Nashville, Chattanooga & St. Louis Railway, under the direction of George M. Carpenter, fuel inspector, may be of interest.

The standard sizes of buggies, holding two and three tons of run of mine coal each, are in use. It is the duty of the foreman at each chute to see that these are filled to capacity, and a report is made to the fuel inspector each day as to the initial and number of the car from which each buggy is loaded, and the number of the engine to which it is delivered. The fuel inspector can therefore check the weight of each car as against the mine weights, can easily find what kind of coal was used on any engine, and in case of poor coal can at once take the matter up with the inspector at the mine from which the coal was shipped.

The tanks on all engines are graduated for each ton, the graduation being stenciled on the leg of the tank. This was done by weighing into a buggy one ton of coal, dropping it into the tender, leveling it off to a uniform depth, and making a mark on the leg. This was repeated for each ton until the tank was filled level full. When an engine arrives at the roundhouse, at the end of a run, a man shovels the coal down from the sides and back of the tank, levels it up and marks on a coal ticket the "pounds on arrival." To this is added the amount of coal taken. It is thus possible to determine with a close degree of accuracy the amount of coal used on each trip, and with very little extra expense.

Another of the older types of coaling stations which allows the coal to be measured, is the low trestle type, with different size pockets, into which the coal is shoveled from the cars. This type of station does not permit the use of the self-clearing cars, and is becoming obsolete, but where it is in use, the coal can be measured quite accurately if the pockets are properly calibrated.

With the large overhead storage pockets the problem becomes a more difficult one. The scheme has been tried of suspending the entire pocket, and introducing a weighing dynamometer, but it is of course necessary to have the pocket hang plumb in order to get accurate results; a wind, or an eccentric loading interferes with this.

On the Santa Fe, a Fuel department has been organized, and placed under the direction of the general storekeeper. A fuel supervisor has been appointed on each grand division, who appoints, and is responsible for the work of all employees engaged exclusively in the receiving, storing, delivering of, and accounting for all fuel. He also receives and compiles all reports from the fuel stations, and makes such reports as may be necessary to the auditing or other departments.

Fuel inspectors (about one to each two divisions) report to the fuel supervisor. These inspectors see that capable men are placed in charge at the fuel stations, both day and night. They are expected to keep in close touch with conditions at the various stations, and to take such steps as may be necessary to insure the economical handling of fuel, and to prevent waste. They see that coal chute repairs are promptly and properly made, and that the coal chute pockets are properly marked to determine as closely as possible the actual amount of coal issued. They instruct the coal chute men with regard to overloading the tenders, and also as to the method of making out the daily reports. They should attempt, in conjunction with the engineer, to reduce the issues of fuel as much as possible, by keeping in personal touch with the firemen. They are expected to ride the different engines, instruct the firemen as to the proper methods of firing, and report any mechanical defects. To secure the best results, they are furnished with a daily record of the operation of each coaling station, and also of the fuel performance of each engine.

Each fuel station is in charge of a foreman. He must not only see that the fuel is properly unloaded and stored, but must measure all the fuel issued and make out the fuel tickets. He is also responsible for the proper loading of the tenders.

EDUCATION OF FIREMEN.

The following excellent article on this very important subject is reproduced from the April, 1908, issue of the *American Engineer & Railroad Journal:*

"What is to be expected—

> *When there is only one traveling engineer or fireman to from 400 to 1,500 miles of road.*
>
> *When green firemen are placed on an engine without preliminary instruction as to their work, and are left to shift largely for themselves.*
>
> *When the traveling engineer or fireman is an ex-engineer who was graduated from firing so long ago that his recollections of it are mellowed and softened by age.*
>
> *When a traveling engineer or fireman has grown so portly that he cannot fire more than a few minutes before he is tuckered out—even if he has not a "biled" shirt on.*
>
> *When most roads do not furnish the firemen with any printed instructions as to their duties, and the proper method of firing, but often rely upon an inefficient force of traveling instructors who, in some instances are entirely unsuited for this work.*

> *When absolutely no record is kept of the coal performance of the different crews—in order that the poor firemen may be located and followed up; or if one is kept it is not issued until from 20 to 90 days after the end of the month and is ancient history before it comes to light.*
>
> *When coal performance records entirely disregard the effect of poor dispatching, and conditions not under the control of the engine crew.*
>
> *When the amount of fuel issued is oftentimes guessed at by poorly paid and sometimes ignorant hostlers—not always proof against a good cigar.*
>
> *When the duties of the traveling engineer or fireman often require him to spend the greater part of his time in connection with office work.*
>
> *When the fireman himself is not ambitious, and does not take a proper interest in his work—but what can be expected under some of the conditions mentioned above?*

Traveling Engineers or Firemen.—Investigation shows that about two-thirds of the railroads have no special courses of instruction, or printed matter, to guide the enginemen in the economical use of fuel, but depend entirely upon the traveling engineers, or firemen, to instruct the men. This is all well enough if these men have been properly selected and are the right kind of men; if there are plenty of them, and if they are not loaded down with a lot of other duties which interfere with their riding on the engines, and instructing the men. Unfortunately these ideal conditions do not pertain on many roads.

In discussing the qualifications of the road foreman of engines, D. R. McBain, of the Michigan Central, spoke as follows before the last meeting of the Traveling Engineers' Association:

"Usually men are selected for these positions (road foremen of engines and traveling engineers), who are successful engineers, who are skillful men, and who are thought by their superiors able to impart such information as their success and skill would denote, to the rank and file of enginemen, where needed. The tremendously skillful man is not necessarily the most successful, as he is likely to give his men the idea once expressed in the hearing of the writer by a conductor who was about to start on his first trip in that capacity, that he drew the pay, and what he said 'must go, right or wrong.' A better man for the position of road foreman of engines or traveling engineer, is the man who will do his best to impart to his men such useful information as he is sure of, and discuss with them any other point, and not make a decision until he knows.

"Success and skill are not all that is essential in the road foreman, or traveling engineer. Good judgment, a cool head, a temperate tongue and a 'thick skin' are perhaps the best assets he can have, as without them he is not likely to possess the art of 'approaching' in a satisfactory manner, the rank and file of the enginemen with their various dispositions."

In addition to being a good instructor, and a good "mixer," the traveling engineer should preferably be a young engineer who has had a first-class record as a fireman, and can get down and fire, when necessary. The remark has been made that if a test for traveling engineers was given, similar to that which President Roosevelt arranged for the army officers in connection with riding, equally good results might be brought about.

How can we expect to secure first-class traveling engineers, with the above qualifications, if the railroads are not willing to pay them more than they could make on the first-class runs?

Literature.—About one-third of the railroads use other measures for instructing the enginemen in the economical use of fuel, in addition to the instruction given by the traveling engineers. This consists in some cases of printed instructions as to the economical use of fuel, which are issued to each engineman; in some instances bulletins are sent out from time to time; in still other cases fuel meetings are held.

FUEL OIL TICKET.

Form 1122-C Standard.

Santa Fe   №   39202   M

FUEL OIL TICKET.

Foreman's No.---------- ---------------Station----------190

FOR MIXED AND WORK SERVICE ONLY.

Initials------------------- Engine------------ Train-----------

From------------------------- To-----------------------------

Reading after taking------------------------- Gallons

Reading before taking------------------------- Gallons

Quantity taken------------------------------- Gallons

------------------------------------ Engineer.

------------------------------------ Fireman.

------------------------------------ Fuel Foreman.

Only a few roads issue instruction books. On two roads, the Chicago, Burlington & Quincy, and the Great Northern, these books are quite elaborate. They include a section on economical firing, which treats of the theory of combustion and the proper methods of firing under varying conditions; a chapter on economical boiler feeding and one on the economical use of steam. Other roads furnish booklets, which may be purchased upon the open market, such as "Information," by George M. Carpenter, fuel expert of the Nashville, Chattanooga & St. Louis Ry., or "Fuel Economy," by George H. Baker.

Several roads issue bulletins on fuel economy from time to time. One of the most successful bulletins of this kind is known as "Circular Letter No. 550," issued a number of years ago by R. Quayle, superintendent of motive power of the Chicago & North Western Railway. At that time the question of proper firing was attracting a great deal of attention, and different roads were issuing instructions of various kinds as to the proper use of fuel. Mr. Quayle prepared a letter in which he called attention to the necessity for the cooperation between the engineer and fireman, and followed this with what is known as a chapter of "don'ts." The result was a marked increase in efficiency, and economy. These "don'ts" are as follows:

Don't think because you are only one engineer or fireman, that what you do does not amount to much. It is the little drops of water that make the mighty ocean, and the little grains of sand that make up this earth of ours; so each individual, in the aggregate, can do a great deal. If each engine crew saves one-quarter of a ton or five hundred pounds of coal, this on a thousand locomotives would result in a daily saving of two hundred and fifty tons, or, in round figures, $157,000 a year.

Don't neglect being at roundhouse in ample time to examine the firing tools on the engine before leaving the roundhouse. See that your ashpan, grates and flue-sheets are in good condition to make the run.

Don't fill the boiler full of water as soon as you get out of the house. Leave a space so the injector can be worked to prevent popping, while air pump exhaust is fanning the fire, pumping air to make the terminal air brake test. If you do this your fire will be in better condition to pull out with. The noises of open pop prevent trainmen from locating leaks.

Don't forget to start the lubricator a few minutes before leaving a terminal. Set it to feed regularly. The proper lubrication of valves and cylinders saves coal.

Don't forget when starting trains, to do so carefully, thus preventing damage to drawbars and draft rigging. By so doing you will save serious delays to your own, as well as other trains. All delays mean extra fuel consumption to make up lost time.

Don't neglect using the blow-off cock, as it keeps the boiler clean and water in good condition, and insures better circulation in boiler. Result: Better steaming engine and a saving in coal.

Don't allow the engine to slip. This is an unnecessary waste of coal, wears out tires and rails, causes great damage to pins, axles and running gear, and generally results in spoiling a fire.

Don't pull out of a station with a train (after engine has stood for a while, and fire was allowed to get low) without first giving the fireman a chance to build up the fire. The time lost waiting to do this will save coal, and can better be made up before reaching the next station. Remember this when you get a time order.

Don't leave the reverse lever down in corner longer than necessary when pulling out of stations. No rule can be made to govern how the throttle and reverse lever should be used. This must be acquired by practice, and observing the performance of the engine. Bring the lever up gradually, as speed is acquired. The lever hooked well towards center of quadrant, with throttle well open, usually gives better results than using the throttle to govern the speed. Up to five years ago we considered it good practice with our smaller power to run with wide open throttle, and as short a point of cut-off as possible consistent with weight of train, but in our heavier and larger engines we find that it is better at many times to throttle the engine. Particular attention is called to all wide firebox type locomotives. The engineer can permit the reverse lever in these engines to remain low in the quadrant when starting from a station, for a greater length of time than with the other types of locomotives, without pulling the fire or losing steam. When you are running on short time, it would be good judgment for the engineer to take advantage of this when pulling out from a station. In this engineers will use their best judgment.

Don't put four, or five, or more shovels-full of coal into the fire at once. One or two shovels-full will give better results, and these two should not be thrown in the same spot. It is good practice to fire on one side of the box at one time, and the next time on the other side of the box, in order that the bright fire on one side may take up the gases from the fresh coal on the other side. This will reduce the smoke and give more steam.

Always fire as light as possible consistent with your work. Very heavy firing will make your flues and stay-bolts leak, and in time will crack your fire-box sheets. The reason for this is that when you have a very heavy fire, the air will not pass up through it readily, and the gases pass off, because there is not sufficient oxygen to unite with them to produce combustion, and as the gases must get air from somewhere, the air is then pulled through the fire-door, causing the chilling of flues and sheets as referred to above.

Don't allow steam to escape at pops unnecessarily. Frequent blowing off at pops shows improper judgment, and implies that the engine crew is not practicing economy. Tests have demonstrated that ¼ lb. per second or 15 lbs. per minute is wasted. This amounts to about one ordinary scoopful, and in most cases may as well have been thrown on the ground as into the fire-box. There are only 133 scoops-full in a ton of coal, so you can see that you would only have to have your pops open one hundred and thirty-three minutes in a whole day in order to throw a ton of coal away.

Don't open the fire-box door to prevent steam blowing off at pops when engine is working: dropping dampers is a better practice. The supply of air is cut off, and combustion is partially suspended. When engine stops blowing off, open dampers again, before putting in coal. This method keeps fire in better condition and saves coal. You have no doubt noticed that on Class R locomotives, when working hard on a hill, you have to shut your dampers in order to keep your fire from turning over. This is because the exhaust pulls too much air up through the grates, and causes your coal to be too active, and to prevent this activity of coal as well as increased combustion which follows, we consider it a good thing to drop your dampers, as per above.

Don't insist on having the maximum steam pressure with pops opening occasionally when handling light trains, when less pressure will handle the train on time, thus avoiding the opening of pops.

Don't forget, when engine is shut off for stations, to drop your dampers, opening the fire-box door slightly if necessary, and using the blower to carry off the black smoke.

Don't blame the engine or coal, if engine is not steaming properly, before you have ascertained whether or not both of you are doing your duty. Talk it over; see if injector is not supplying more water than is being used, or that fireman is not firing too light or too heavy. Heavy firing is responsible for more poor steaming engines than the lighter method. You all know some engine crews have better success than others with the same engines and conditions. Think a little: there must be some cause for this.

Don't wait until you get the signal to pull out before building up the fire. This should be done gradually until the proper thickness has been reached. A good fire to start with is essential to maintain the proper steam pressure, while engine is working hard getting train under way. Afterwards distribute the coal evenly on sides, ends and corners. Do this systematically, keeping in mind where you have placed the last shovelful, thus avoiding getting holes in fire, and prevent piling up coal all in one place. Endeavor to keep the steam pressure uniform, with as little black smoke as possible. Experience has taught that engines with draft appliances properly adjusted require very little coal in center of firebox.

Don't permit the water to get so high in boiler that it is carried over into the valves and cylinders. This usually occurs when pulling out of stations, and the water carries off the oil, which not only results in cut valves and cylinders, but the extra friction damages the entire valve motion, to the detriment of the power of engine and the coal record.

Don't gauge the amount of water an engine will safely carry by water coming out of stack. Keep it low enough to insure dry steam being used, because moist steam has the same effect as water. Usually one-half glass, or two gauges give best results. Be careful, however, that when ascending a grade, and you are about to pitch over the other side, that you have sufficient water to keep your crown-sheet thoroughly covered. If your custom has been to carry high water, try less and note results in better handling of tonnage, also saving in coal and oil.

Don't neglect to take advantage of your excess steam before your engine is about to pop off, by making a heater of your injector, blowing steam back into the tank to warm the cold water, but avoid getting it so hot that the injector will not lift the water. By doing this you will keep your engine from blowing off at pops, when standing at stations after the boiler is filled up. You have all tried warming the water in the tank to help a poor steaming engine, with good results. What is good for a poor steaming engine will surely help a good steaming engine do better. Try it, and you will find that it will not only save work for the fireman, but will make a better coal record for the engine crew, besides keeping the tank from sweating, which you are aware spoils paint.

Don't think the fireman alone is to blame for your coal record. The best and most economical fireman cannot make a showing with an engineer who supplies more water to the boiler than is being used, and who shuts injector off only when boiler is pumped full. The proper handling of the injector is one of the most important matters in saving coal. Feed water to boiler, according to demands. If on through train, keep water level as possible. If on way freight or switch trains, lose a little water between stations. Fill up again while drifting into, standing or switching at station. The advantages of supplying less water than is being used between stations are: It requires less coal to keep up steam pressure when running; also leaves a space so injector can be worked to avoid pops opening, and heavier fire can also be maintained to do switching, without the possibility of the fire being pulled.

Don't pull out, after making a stop, with injectors working. The cool water introduced during period throttle was shut off is put in circulation throughout the boiler, and pointer on gauge drops back from five to twenty-five pounds. The fireman must then fire heavier to regain the lost steam, and naturally will use more coal. This condition exists also when engine has gone down grade with throttle shut, or slightly open. Shut the injector off before opening the throttle. If this is not your practice, try it and note the difference.

Don't wait for the pops to open, and use this as a signal to put on the injector. Keep an eye on the air gauge, steam gauge, and water glass. You all know this can be done without detracting your attention from the track ahead. A look for an instant every mile or two will keep you informed, and is a good habit. Doing this will also keep you posted on air pressure, and may avoid difficulties should the air pump stop. The fireman should also keep an eye on the water glass, as the engineer is sometimes compelled to keep the injector at work to prevent the engine blowing off. When glass is full the fireman should fire lighter, to give the engineer a chance to shut off the injector, and not have engine blow off. However, this condition should only exist when injector cannot be worked fine enough to just supply amount used. This sometimes occurs when card time is slow, or on down grade, or when running with light train.

Don't put too much coal under the arch of engines with sloping fire-boxes, because these engines naturally pull the coal ahead, which results in forward section of grates becoming stuck and clinkered over, and fire is pulled in back end of fire-box. Experience and observation will teach you to put most of the coal in back end of fire-box.

Don't think engine having two fire-box doors requires twice the quantity of coal it would if it had but one. The extra door is for the purpose of distributing the coal more evenly over the grate surface, with less effort on the part of the fireman.

Don't shovel large chunks of coal into fire-box, because you find them on the tank. The coal house men have instructions to break it the size of an apple. If not properly broken, report it to road foreman of engines or master mechanic, instead of fellow engineers or firemen, but don't think it a hardship to break some occasionally. Better break it than to throw in large chunks. They are foundations for clinkers.

Don't expect the fireman to fire the engine with one or two scoops-full to each fire, and also ring the bell for highway crossings and stations. Some engineers expect this. If engine is equipped with an air bell-ringer, get into the habit of starting the bell-ringer when blowing the whistle. By so doing, the habit will become as fixed, as whistling for crossings and stations. Besides, it is just as important. Remember the engineer is responsible.

Don't put in a heavy fire about the time the engine is shut off for a station, or down-grade. The heavy cloud of black smoke is evidence the engine crew is not working in harmony or practicing economy. If on train that stops at all stations, the fireman should guard against it and learn when to stop firing. He will be governed by grade, service, and weather conditions. If train does not make all station stops, the engineer should keep the fireman informed of intended stops.

Don't forget that different qualities of coal, and different makes of grate used, govern the shaking of grates. Coal that fills up and clinkers, requires more attention than the better grade. The object is to keep the grates free, so the proper amount of air can be admitted.

Don't neglect cleaning your fire on trains that are long hours on the road. Make use of the first opportunity. You will get better results with less labor and coal, and avoid leaky flues. Better clean out a small amount two or three times, than not clean it at all.

Don't take coal or water oftener than necessary, as it requires an extra amount of coal to again get a heavy train in motion, especially on a grade. Good judgment is required, in order not to run short before getting to next coal chute, or water tank. Where possible, take water only from tank containing good water.

Don't forget that leaks in the air pressure are being kept up by an equal amount of steam pressure. As it takes coal to make steam, air leakage means a waste of coal. Keep apparatus on your engine tight, and insist on trainmen doing their part.

Don't try to put more coal on tank than will lay on it securely. All coal dropped off by overloading is wasted; also keep coal from falling out of gangway when running. This may be only a little each day, but it all counts against your coal records, and besides it looks badly when strewn along the track. You cannot save coal by the ton; it must be in pounds, which in time make tons.

Don't forget to make an intelligent report on your work slip, on arrival at roundhouse. Consult your fireman in regard to any defect that has come to his notice, especially with grates, dampers, or firing tools.

Don't neglect reporting the pop valves ground in, when leaking, or when they blow back eight or ten pounds before seating. Also report leaky piston rod, and valve stem packings, or if cylinder packing, or valves are blowing. All these leaks draw on the coal pile unnecessarily; it takes coal to generate the wasted steam. This also applies to leaky steam heat appliances, cylinder cocks, etc.

Don't neglect looking at coal report each month, to see how you stand in relation to others in same service with whom you are comparable. The other crews get the same pay you do, and it should be your aim to be as economical with both fuel and supplies as they are, other things being equal. Keep posted, and be with the average. It will be to your credit and interest some time; therefore aim to be at the top.

Don't think when coal report shows you using only two pounds more per 100-ton mile than other crews in same service, it is close enough. This means two pounds more used for every mile you hauled 100 tons; or another way, two pounds for every 100 tons hauled one mile. Figure this up, and you will find in hauling 100 tons 100 miles, a difference of 2,000 pounds, or one ton. This method of showing up the individual record is more equitable to all, than on basis of miles run per ton of coal.

Don't think after reading over this chapter of DONT'S you should save coal to the detriment of the service. The actual amount required to make up time, keep on time, or handle tonnage, is not what we are trying to save; it is the waste. You will notice, the proper method of handling the engine, to the extent of economical use of fuel only has been considered.

FUEL MEETINGS.

On several roads, fuel meetings are held from time to time. On the Chicago, Milwaukee & St. Paul, these coal meetings are held at the various division points three or four times a year. In addition to the engineers, firemen, and mechanical officials, the local operating officials are also present. The men are encouraged to express their views, and criticize methods, and these meetings have been instrumental in bringing about splendid results, not only as concerns the work of the engine crew, but also in connection with the operation of trains. On another road in the Middle West, the assistant superintendents of motive power recently went over the divisions where they were best acquainted, and hired halls, and talked to the enginemen on the economical use of coal.

LOCOMOTIVE FIRING.

The possibilities of fuel saving are probably greater after the coal has been placed upon the locomotive tender than at any other point in its journey from the mine to the ashpan. Considering a great majority of the locomotives in this country, which are easily within the capabilities of hand firing, and placing the limit at possibly two tons of coal per hour burned, we know that there is an enormous amount of waste, and in most cases needless waste, going on all of the time.

The qualifications of a good fireman are, first, intelligence or brightness, and, secondly, physical strength and endurance. In a great majority of cases no large amount of strength is required for proper firing, in itself, and that factor enters into this problem, the same as it does in all similar lines of activity, only when the action is constant and continued for a long period of time. Even then we find that the best firemen are not usually those who can raise the heaviest weight, but rather the men of moderate strength and great endurance. They are the fellows who fire properly and keep everlastingly at it. Your strong man will handle more coal and work harder; will be exhausted and require a longer period of rest, all because he has performed much useless labor and incidentally has needlessly thrown away a large amount of valuable coal. Comparisons between the small wiry chap, who uses his head, and the big, strong fellow, who heaves coal, are present at every division point in this country, and almost universally result in the favor of the former, provided, of course, he has been given the proper instruction.

A few of the companies are furnishing their men with literature, going more or less fully into the theory of combustion, and giving detailed instructions as to the proper method of firing, and still fewer have followed this up with a thorough course of individual instruction, but a very great majority have done neither, and practically allow a new fireman to learn his business as best he can from his associates.

On divisions where the proper grade of men can be obtained and the work of instruction is systematically and conscientiously followed out, most gratifying results in the shape of improved fuel records, increased interest in the work, and a contented and loyal set of firemen, are possible. Upon the other hand where either a low grade of men is all that is available, or where the work of instruction is done in a half-hearted or slip-shod way by incompetent instructors, the education of the fireman is bound to be a failure in all ways. There will always, of course, be individual cases that it will be impossible to do anything with. These will usually be found to be confined to the man with a strong back and a weak head (which some one has facetiously stated should be the qualifications of a fireman), who can get over the road because of his strength, but cases of good firemen quitting because they could not stand the work, which was easily within their strength if they had been properly instructed, are not by any means uncommon throughout the country, and it is this feature that causes the greatest regret that more attention is not being given to the subject of education. If you cannot get firemen of sufficient intelligence it is unfortunate, but if you don't keep those who are capable of learning, there is certainly a grave fault somewhere.

The lines that should be followed in educating the firemen are covered in a general way in a previous section. As far as the actual placing of the coal on the fire is concerned they consist very largely in convincing the men, both by sound reasoning and actual example, that it will pay, and pay well, to scatter well broken coal in small amounts on various parts of the grate in succession, with such an interval between charges as will make it necessary to again cover the first point as soon as the whole grate area has been gone over. This, of course, with the ordinary locomotive, means continuous, but in most cases, leisurely, work and gives no time for the seat box or anything else while the locomotive is working at full power. Opportunities for the needed rest will be given on the down grade stretches, the stops for water, the waits at meeting points or for orders, and the shut-offs for signals, flags, etc. This is the way firemen should fire and the way an intelligent educated fireman will fire, *provided* he is not expected to take care of ten or fifteen other things at the same time. He cannot and will not do it if he has to break all his coal; if he has to climb up and shovel it down from the back of the tender every half hour or so; if he is expected to see every signal; if he has to clean out the ashpan at every stop for water; if he has to work against an injector that "forgets," or a couple of extra notches on the quadrant; if he is given dirt and slack for coal; if the competitive coal records are based on the guesses of an ignorant coal chute hand; if the records are posted six weeks after they are made; if an engine rated at 2,000 tons is habitually given 2,200 tons, etc., etc.

The education of firemen will pay if it is given a chance, but there is no use in teaching a man to do a thing properly and then arranging conditions so that it will be impossible for him to do it that way. Give a fireman a small shovel, not over 15 lbs. capacity, an automatic door opener and decent coal; teach him how to fire and if he is not loaded down with other duties and handicaps you will be surprised how little coal he will burn per ton mile or per car mile, as well as in the reduction of engine failures due to leaky flues and fireboxes.

Of course, there are many conditions affecting the efficiency of the firemen, over which the motive power department has no control, and many others over which no one has control, all of which tend to neutralize the value of the properly educated fireman. But there are enough which can be controlled to make it very advisable to accompany a scheme of training firemen with a course of education and improvement along other lines. It is not an impossible condition to find master mechanics and even higher officials who are also in need of a little educating in things which directly concern the firemen and the fuel bill.

There is one condition, however, which no amount of training or education will improve, and that is a locomotive of a size and power which no man can shovel coal enough into, properly or improperly, to develop its capacity. This would also include those locomotives which are capable of hand firing, only when everything is in perfect shape, and fall down under ordinary adverse conditions. At the present time there is no very large number of locomotives running in this country which would come strictly under this head and if we had only to consider these, there would be no great demand for mechanical stokers. There are, however, a large number of big engines which, from causes beyond the mechanical department's control, and seemingly incapable of correction, a few of which have been mentioned, are not able to give their full power with hand firing.

At some points it is impossible to get men for firemen who are of a sufficiently high order of intelligence to be able to learn to fire properly and economically. This may be due to a poor source of supply; to a rush of business compelling the acceptance of any one, or to working conditions and surroundings, which no self-respecting man will put up with. No matter what may be the cause of their presence, such men will not be able to develop the full power of a big locomotive, over a division of average length. Again it may be very desirable, and possibly profitable to use a grade of fuel which is so high in ash and impurities as to compel a man to get it into the fire-box as fast as he can, in order to have time to shake the grates. He certainly cannot properly develop the full power of the locomotive under these conditions, even if the fuel is capable of doing it at all. Thus, there are four conditions which are beyond correction by the proper education and training of the fireman, and even beyond correction by the mechanical department. These are: Very large engines, operating conditions making proper firing impossible; low grade of men, and use of low grade fuels. Under such conditions the only remedy would seem to be the mechanical stoker, reference to which has already been made in another portion of this book.

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